DISCUSSION

PRESENT DAY WATER FILTRATION

By George A. Johnson

A paper read at the March meeting of the New York section and printed in Journal of the American Water Works Association, Vol. 1, No. 1, at pp. 31–80.

Mr. John H. Gregory: The author has presented a paper which contains much of interest to water works engineers and superintendents interested in filtration, and there is much in the paper with which the speaker is in hearty accord. There are, however, some phases of the subject on which the speaker holds somewhat different views from those of the author, among which may be mentioned the questions of the cost and difficulty of securing sites for slow sand filters and those of the cost of both slow and rapid sand filters.

The author states:

> It is true, on account of the much greater area required, the cost for land is far greater in the case of slow sand filtration systems than for rapid sand systems. Roughly, other things being equal, land will cost twenty times as much for a slow sand filter installation as for a rapid sand plant.

There is but little question that, under ordinary conditions, the cost of land for slow sand filters will exceed that for rapid sand filters, owing to the larger area required, but that it will amount to as much as "twenty times" that for slow sand filters is open to question. Those who have had experience in acquiring land for water works projects know that, even if only a small piece of land is required on which to locate the works, but that this piece of land is a portion of a much larger tract, the purchaser might often as well buy the whole tract of land as to buy only a small portion of it. Thus it may readily be that, in acquiring a site for rapid sand filters, much more land would be actually purchased than needed simply for the plant. It may be that the area required for the construc-

tion of a slow sand filter plant will be twenty times that required for a rapid sand filter plant but that the land will cost twenty times as much does not necessarily follow.

In discussing further the question of site the author states:

> Furthermore, in large projects, it is often difficult conveniently to locate a site for slow sand filters, while for a rapid sand filter plant it is a relatively easy matter as a rule. If it is necessary to go a long distance in locating an extensive and suitable area of land for a slow sand filter site there is incurred a large expense for a conduit to bring the filtered water to the city.

The inference might be drawn from this that it has been exceedingly difficult to secure sites for large slow sand filter plants, but the history of many of the plants which have been built will hardly bear out this inference.

In commenting on some of the plants which the author mentions in the table on page 69 the speaker might say that he has been personally connected with seven out of the fifteen plants mentioned and is familiar with the reasons which led to the selections of the sites on which these works were built. It is, of course, necessary to have land on which to build filters, whether of the slow or rapid sand type, but in the selection of a site local conditions are often a very important factor.

At Albany, New York, for example, practically the first ground available on which filters of either type could be built and which could be purchased at a reasonable price, was that on which the slow sand filters were actually built, just north of the city line. It happened that there was another tract of land a little nearer to the existing water works pumping station, to which the filtered water was to be delivered, where it would have been possible to build either slow or rapid sand filters. To have acquired land there, however, for either type of filters, would have been very expensive. The site on which the filters were built had another advantage in that the intake there would be further away from local sources of pollution; at Albany the Hudson River is tidal; the sewage from the city was and still is discharged into the river without treatment and on flood tides there is often an upstream current which carries some sewage with it. It will be seen then that other factors than simply area of land alone may have a bearing.

At Pittsburgh, Pennsylvania, as far as the speaker is aware, no difficulty was found in securing a site for the slow sand filters which

plant is one of the largest in the world. The filter plant is located directly across the Allegheny River from the Brilliant pumping station, from which most of the water used in the city is pumped. It is true that it was necessary to build conduits under the river to bring the filtered water to the pumping station, but the case would have been the same if rapid filters had been built instead, for, if the speaker's memory is correct, the best site on which filters of either type could have been built was that on which the slow sand filters were constructed.

For the four slow sand filter plants in Philadelphia mentioned by the author, namely, Torresdale, Upper Roxboro, Lower Roxboro and Belmont, and of which the speaker had charge of the design, no trouble was experienced in securing suitable sites.

As regards the Lower and Upper Roxboro filter plants, local conditions were of the greatest importance in that it was necessary to utilize existing reservoirs as settling basins, as well as existing pumping stations and pipe lines. Somewhat similar conditions existed with reference to the Belmont plant although in this case there was no reservoir which could be utilized as a settling basin.

The Torresdale slow sand filter plant is the largest single plant in the world, and if difficulty had been experienced in securing suitable sites for such works it would naturally be expected to have occurred here. Such was not the case, however, and the plant was built inside the city limits. It is true that the plant was located some distance up stream from the closely built-up part of the city, and that a conduit about 2½ miles in length was constructed through which filtered water is delivered to the Lardner's Point pumping station, but it was good judgment on the part of the city authorities to locate the works where they did.

The Delaware River at Philadelphia is tidal and is polluted by the discharge of sewage from the city, and it was to avoid pollution as well as to secure a site that the plant was built as far upstream as it was. It might be added further that the city has already constructed a small sewage disposal works just below the Torresdale filter plant, where sewage is treated and the effluent disinfected before discharge into the river, in order to guard against raw sewage from the nearest point reaching the intake of the Torresdale filters. Had rapid sand instead of slow sand filters been built at Torresdale there is no question in the speaker's mind but that such a plant would have been built as far upstream as were the slow sand filters.

One might fancy possibly that trouble would be experienced by the city of New York in securing sites for filters. Such is not the case. Over ten years ago the commission on additional water supply, in its investigations for an additional water supply for New York City, looked into the question of filter sites not only for the additional supply but also for the Croton supply. Sites were found where slow sand filters could be built in close proximity to the existing Croton Aqueduct, and sites for slow sand filters were also found and surveyed where the additional supply could be filtered along the line of the proposed new aqueduct. Some years later the department of water supply actually prepared detailed plans for a slow sand filter plant for the Croton supply, on a site located in New York City, namely, in the east basin of Jerome Park Reservoir, the construction of which was suspended pending a decision as to the filtering of the supply. In the case of New York City it is not a question of going a long distance and building an expensive conduit to get a filter site, but rather a question of going a long distance and building an expensive conduit to get water.

At Cincinnati, Ohio, the rapid sand filter plant, which is the largest of its kind in operation in the world, was built well upstream above the city where plenty of land was available for either rapid or slow sand filters. The filtered water is discharged through a long conduit to the main pumping station from which it is pumped to the reservoirs in Eden Park. This plant was built for the future as well as for the present and it was good judgment to locate the plant as far upstream as it is.

At Columbus, Ohio, the rapid sand filters were built at some little distance upstream above the city. It was a case here of going upstream to get out of the flood zone, although sufficient land for either rapid or slow sand filters was available nearer the city. At the point where the plant was finally built there was sufficient land for either rapid or slow sand filters. In acquiring the land for this particular plant it was found that it would be about as cheap to acquire the whole tract of land on which the works were built as to acquire only so much of the same as would be needed for the plant alone.

Perhaps enough has been said to point out that factors other than the area of land alone have to be taken into account, for slow as well as for rapid sand filters, in selecting a suitable site.

The author also considers, in the table on page 69, the cost of

construction of different types of filters. It is exceedingly difficult to compare satisfactorily the costs of construction of different plants, even where the fullest information regarding the same is available. Those who are not well posted as to the history of some of the plants cited in the table may possibly be misled as to the cost of building both slow and rapid sand filters if they accept the figures of the author without full knowledge of local conditions.

One of the features which very materially affects the cost of such works is the total reservoir capacity provided, that is the combined capacity of the settling basins and of the clear water reservoirs. To illustrate: The rapid sand filter plant at Little Falls, New Jersey, which, in the author's table is the most expensive one cited, and which cost $15,000 per million gallons daily capacity, has a coagulating basin capacity of 1.3 hours and a filtered water reservoir capacity of 2.6 hours, or 3.9 hours total reservoir capacity. At Columbus, Ohio, the rapid sand filter plant, which the author states cost $13,000 per million gallons daily capacity, the next to the highest in cost cited, has a settling basin capacity of 12 hours and a filtered water reservoir capacity of 8 hours, making a total reservoir capacity of 20 hours, or five times as much reservoir capacity as that of the Little Falls plant. If the reservoir capacity of the Little Falls plant had been approximately that of the Columbus plant the cost of construction of the Little Falls plant would have been materially increased over that given by the author. Again, the New Orleans rapid sand filter plant might be cited, which has 35.2 hours total reservoir capacity, or practically nine times as much reservoir capacity as that of the Little Falls plant. Other factors which affect the cost of construction are the character of the raw water, the rate of filtration, the character of the construction of the works, etc.

In his reference to the Albany slow sand filter plant the author gives its capacity as 20,000,000 gallons daily. The Albany plant as originally built before the pre-filters were added, had a capacity of 15,000,000 gallons daily. The addition of the pre-filters increased the capacity of the plant very materially so that at the present time the capacity is probably in the neighborhood of 28,000,000 gallons daily. If the capacity is taken at 28,000,000 instead of 20,000,000 gallons daily the cost of the plant would be about $14,300 instead of $20,000 per million gallons daily capacity as given by the author.

The Philadelphia slow sand filter plants were expensive plants to build. They differ in one way from many of the other filters of

the same type that have been built in that, underneath the filter floors and carried up all around the sides of the filters, is a layer of puddle. This item alone materially increased the cost of construction. The Lower Roxboro and Upper Roxboro plants were built on high ground in an isolated section several miles from the nearest railroad, and the cost of delivering materials to such plants was higher than would ordinarily be the case.

In the cost of the Lower Roxboro plant the author did not include the cost of the Lower Roxboro reservoir which was built many years before, and which supplies settled water to the filter plant. Again, a similar condition exists at the Upper Roxboro filter plant with regard to the settling basin. The New Roxboro reservoir was built some ten years earlier than the filter plant, and the author has not included its cost in the cost of the filter plant. Strictly speaking, the costs of the reservoirs should be included in the costs of these two plants so that the figures would be comparable with the costs of the other slow sand filters cited.

The Philadelphia plants were built during a régime of very high prices, and to use the costs of construction of these plants to indicate the reasonable cost of slow sand filters may be very misleading except to those who are familiar with the early history of these works, and who are aware that the costs were high and that the plants could be duplicated at less cost.

The largest slow sand filter plant under construction in America at the present time is at Montreal, and, when completed next year, will have a capacity of 60,000,000 United States gallons daily. The total cost of the plant, on the basis of the lump sum contract prices, including the low lift pumping station, will be about $22,600 per million gallons daily capacity. Deducting the low lift pumping station the cost will probably be about $21,000 per million gallons daily capacity.

It would have been interesting if the author had cited the cost of the slow sand filter plant which was completed at Toronto about two years ago. This plant has a capacity of 48,000,000 United States gallons daily, assuming one-sixth of the filter area to be held in reserve, and based on a rate of filtration of 6,000,000 United States gallons per acre daily, the rate for which the plant was designed. The cost of the plant, omitting the low lift pumping station, was only about $12,700 per million gallons daily capacity.

In considering the weighted average cost of slow sand filters given

by the author, namely $32,600 per million gallons daily capacity, it may be well to bear in mind that the Montreal plant will cost only about $21,000, that the Albany plant cost about $14,300 and the Toronto plant only $12,700 per million gallons daily capacity.

In referring to the cost of rapid sand filter plants the author cites the Columbus plant as costing $13,000 per million gallons daily capacity. This plant was designed and built under the speaker's direction and is a water-softening as well as a rapid sand filter plant. The cost of this plant was given in great detail in a paper[1] read by the speaker some years ago. The speaker is not informed as to what items the author included in arriving at the cost of the Columbus plant, but in the speaker's judgment the Columbus plant, considered as a rapid sand filter plant alone, cost nearer $15,000 than $13,000 per million gallons daily capacity, the figure given by the author.

Another rapid sand filter plant which the author might have cited is that at Toledo, Ohio, the cost of which was published in the *Engineering Record*, November 26, 1910. Part of the plant was built for a capacity of 60,000,000 gallons daily, although the present capacity of the works is considerably less. Including only such items as are chargeable to the filter plant proper the works cost about $14,500 per million gallons daily capacity.

Another rapid sand filter plant which might have been cited is that at Grand Rapids, Michigan. The plant was completed inside of the last two years and has a capacity of 20,000,000 gallons daily. The cost of the plant, as given to the speaker by the Grand Rapids officials last year, including such items as are chargeable to the filter plant proper, was $16,300 per million gallons daily capacity.

In December, 1912, the city of New York received bids for a rapid sand filter plant to be located at Jerome Park reservoir and having a capacity of 320,000,000 gallons daily. The speaker is more or less familiar with the plans for the proposed Jerome Park filters as he served as one of a commission of engineers appointed by the board of estimate of New York City to report on the same. Taking the lowest bid received and adding to it the cost of the buildings and other necessary work, the Jerome Park filter plant, which would have been the largest rapid sand filter plant in the world, would have cost about $18,400 per million gallons daily capacity. When the plant is built, and it is greatly to be hoped it will be built soon,

[1] *Trans. Am. Soc. C. E.*, vol. lxvii, 1910.

the actual cost will probably be in the neighborhood of $20,000 per million gallons daily capacity, as much of the excavation for the plant has already been completed.

The author gives the cost of the Cincinnati rapid sand filter plant, which has a daily capacity of 112,000,000 gallons, as $11,400 per million gallons daily capacity, and states that the cost of the large, plain sedimentation basins is not included. At Cincinnati there are two large settling basins to which the raw water from the Ohio River is pumped. The water is first settled in these two basins, and is then delivered to the coagulating basins at the filter plant. There is no question in the speaker's mind but that the settling basins are part of the filter plant at Cincinnati, but just how much of the cost of the same should be chargeable to the filter plant may be a question. Mr. J. W. Ellms, the superintendent in charge of the filters at Cincinnati, in a paper printed in the *Journal of the Association of Engineering Societies* in January, 1912, states:

> The settling reservoirs, which have a capacity of 330,000,000 gallons of available water, are in part a portion of the water purification plant, although they also serve the purpose of storage basins and were designed for such a use quite as much as they were for sedimentation purposes.

The two settling basins cost $1,521,000, or about $13,600 per million gallons daily capacity of filter plant. Adding this cost to that of the filter plant would give a total cost of $25,000 per million gallons daily capacity. As the settling basins serve as storage reservoirs also it may be reasonable to charge the filter plant with perhaps only half their cost. On this assumption the cost of the settling reservoirs chargeable to the filter plant would be $6,800 per million gallons daily capacity, thus making the total cost of the filter plant $18,200 per million gallons daily capacity.

Still another plant which the author might have cited, and among the best in the country, is that at New Orleans, which has a capacity of 40,000,000 gallons daily. Including only such items as are chargeable to the filter plant proper the cost of the New Orleans plant was about $30,200 per million gallons daily capacity.

The weighted average cost of the Columbus, Toledo, Grand Rapids, Cincinnati and New Orleans rapid sand filter plants, is $18,600 per million gallons daily capacity, while the author gives a weighted average cost for rapid sand filters as $12,100. In other words, the weighted average cost of the five plants just cited, all of which are

in operation and which are among the best in the country, is over 50 per cent higher than the weighted average cost given by the author.

The speaker has but little further to say on the subject of cost except that, in his judgment, the weighted average costs as given by the author are too high for slow sand filters and are too low for rapid sand filters. Similarly the fixed charges on the costs of construction would respectively be too high for slow sand and too low for rapid sand filters.

The speaker is not presenting any brief for slow sand filters. The rapid sand filter is more flexible than the slow sand filter and in the majority of cases in the United States is better adapted to the purification of water than is the slow sand filter. The slow sand filter has done and is still doing good work in this country, and the present status of water purification is, to a large extent, due to the introduction of the slow sand filter.

Mr. George C. Whipple (*by letter*): The writer believes most thoroughly in mechanical filtration. He also believes in sand filtration, and does not agree with Mr. Johnson that this method is becoming obsolete.

It is perfectly true that there have been more mechanical filters introduced during recent years than sand filters. This is wholly proper and natural, for, as he states, a majority of American cities use waters for which mechanical filtration is better adapted than sand filtration, namely, turbid waters and colored waters. It is also true that the possibility of disinfecting water readily and at low cost by means of liquid chlorine or calcium hypochlorite has somewhat broadened the field of the mechanical filter. These facts are well known to all sanitary engineers, most of whom, however, will not admit that sand filters are obsolete. To do so would be to ignore the filtration practice of a very large part of the world.

Mr. Johnson has given an excellent historical review of the subject, and he has done well in emphasizing the very great need of careful supervision of all filter plants, whether sand or mechanical.

The section of his paper devoted to the relative costs of slow sand and rapid filtration is incomplete, misleading and illogical. His figures are of little use to engineers, and it is to be hoped that they will not be quoted in such a way as to mislead laymen unfamiliar with the subject.

In the first place, no statistics of cost are given, but merely the rate of cost per million gallons capacity. The reader, therefore, has no opportunity of ascertaining in what manner the computations are made. In some cases also the figures are quite evidently unreliable, as the footnotes to the tables themselves indicate. In the second place, figures are given for only fifteen filter plants out of several hundred which are now in operation. In the third place, the final comparison of cost is based on weighted averages, which unduly emphasize the costs of the plants of larger capacity. The very great range in the few costs that are given emphasizes the need of great caution in using them.

A comparison of the cost of filtration by the two processes is, of course, a matter of interest, but it must be a general, rather than a specific interest, for in any particular case the true comparison is between the cost of the two processes applied to local conditions.

Again, the statement that slow sand filtration is out of its element where chemicals are required is absurd. One only has to study the cost and results of filtration at Washington, D. C., and at Springfield, Massachusetts, to learn that chemicals may be economically applied with great benefit to waters filtered by slow sand processes.

Another statement to which exception should be made is:

> The hygienic efficiency of water filtration processes measured by the reduction in typhoid fever may be said to be about 70 per cent.

The hygienic efficiency is actually far greater than this, being nearer 100 per cent than 70 per cent, that is to say, practically all of the water-borne typhoid fever is eliminated. It is well known that typhoid fever is transmitted in many other ways than by public water supplies, and in measuring the efficiency of water filtration these should be entirely left out of the count. The author is quite right, however, in saying that both sand and mechanical filtration, if properly operated, are capable of preventing the spread of water-borne diseases, and from a hygienic standpoint, there is little to choose between the two methods.

Quite as much depends upon the manner in which the filters are operated as upon the type of filter installed. Poor operation of mechanical filters is likely to do more damage than poor operation of slow sand filters. The greatest difference, however, is not so much dependent upon the type of filtration as upon the size of the plant. Generally speaking, the large plants receive a much higher

degree of supervision than smaller plants, and one of the problems which sanitary engineers have most at heart at the present time is that of securing more efficient operation of small filters. Until better supervision can be secured, it is wise to utilize the natural purifying influences that come with long storage to as great an extent as possible. From a hygienic standpoint storage is of greater benefit to a small water works than to a large water works system.

In conclusion, the writer feels that most water works superintendents will sympathize with King James, referred to by Mr. Johnson, preferring shoes that are easier for the feet to those that pinch and produce corns and bunions. It seems to the writer that it is high time for engineers to cease talking about the relative merits of sand filtration and mechanical filtration, in fact most sanitary engineers have long since done so, and recognize that both sand and mechanical filtration have their proper place in water works practice.

Mr. P. A. Maignen: The speaker has had no time to read the paper before this morning and has just run through it and finds two passages which give occasion for saying a few words. The author, on page 39, states:

> The residual turbidity in the effluent of this preparatory process is caused by suspended matter in a state of fine sub-division. This matter, when applied to slow sand filters, penetrates deeply. . . . . The penetration of suspended matter into the beds is sometimes as great as 10 inches.

Now it may be asked: Is this penetration of fine mud into the interstices of the sand a good or a bad thing? Is not the filtration likely to be of better quality? Do not the filters work longer without cleaning? At the origin of slow sand filters it was usual in London and Paris to run raw water on to the filters to fill up the interstices of the sand at the surface and make that once celebrated thing which was called Schmutzdeke. The only objection that can be made to the deep penetration is that when the sand has to be cleaned more of it has to be handled, but then it goes longer without cleaning so that the cost per million gallons of water filtered is not materially different, and if anything, the filtrate is probably better. It was to obviate this penetration that an artificial Schmutzdeke was designed of fine fibre such as asbestos fibre, or of other fine filtering material, such as coke or charcoal, to be deposited on the surface of the sand at the beginning of an operation as the mud of the raw water used to be applied.

The first work done in the way of preliminary filtration in this country was done in Philadelphia, at the Lower Roxboro Plant, after a very elaborate and prolonged study in the laboratory and experimental plant, and also in the testing plant of the city of Philadelphia at Spring Garden Street. This study has clearly established the fact, for the first time in the history of filtration, that it would be possible to obtain a speed of 6,000,000 gallons per acre per day from slow sand beds instead of 2,000,000 or 3,000,000, previously obtained. The preliminary filtration was then found to remove from 60 to 75 per cent of the suspended matter and of the bacteria, and of course rendered the work of the final filter easier and safer. A second system of preliminary filtration was installed at Belmont Station of the city of Philadelphia water purifying system. Preliminary filtration has been applied with considerable success and rendered possible the effective work of the filter plants designed for South Bethlehem and Lancaster.

Too much should not be expected from preliminary filtration. It was not intended to retain the fine suspended matter referred to above. Its very words show that it was to retain the coarsest materials, and by one of those unexplained phenomena the bacterial efficiency of this coarse filter has been extraordinary, averaging fully, when properly conducted, 75 per cent. If the chemical treatment of water is objected to, there is no other way known to the speaker to make the slow sand filters effective, when the water is charged with the fine suspended matter in question, but to use an artificial Schmutzdeke on the sand itself.

The author of the paper, on page 79 refers to:

> That slow sand filters, without the aid of costly preparatory treatment, cannot efficiently purify such waters as those of the Hudson River at Albany, the Delaware River at Philadelphia, the Potomac River at Washington, and the Allegheny at Pittsburgh. And even with preliminary filters there are cases where not only the appearance of the slow sand filtered water is at times unsatisfactory.

This can be done by means of an artificial Schmutzdeke, but special design of the filter beds is to be resorted to for the proper distribution of same as was done at Lancaster and Bethlehem.

Mr. W. C. Hawley: The results given for the Pittsburgh filter plant are extremely interesting and probably explain the reason why so little has been printed regarding the operation of that plant.

The conditions in the Allegheny River are extremely difficult to handle, and while in the light of the state of the art at that time, doubtless good judgment was used in deciding upon a slow sand filter plant, it is at least probable that, if the problem was to be considered today, mechanical filtration would be adopted.

It may prove of interest to give, by way of comparison, results obtained by a mechanical filter plant filtering water obtained from the Allegheny River only a short distance, perhaps 1000 feet, above the intake of the Pittsburgh plant. This plant was built in 1909–10 by the Pennsylvania Water Company.

The Pennsylvania Water Company was supplying at that time a population of about 80,000 people and large industrial establishments, and was pumping about 10,000,000 gallons a day. The company had been obtaining its supply for some years from filter cribs located in the bottom of the Allegheny River, which have been described so frequently that it is not necessary to go into that matter at this time. The filter plant was designed to take advantage of the purification which the cribs would perform, thereby reducing the work to be done by the filter plant. This not only reduced the cost of the filter plant, but our experience has demonstrated the advisability of the use of similar cribs, to a certain extent at least, in filter plants similarly located. The advantage of these cribs is that they give a water of more or less uniform alkalinity, always sufficient to react upon the coagulant, and a material reduction in bacteria, turbidity and color. This is because a considerable proportion of the water taken from the cribs comes from an underground source and is not merely filtered from the river.

The filter plant is of the ordinary mechanical type with an ultimate capacity of 20,000,000 gallons a day. It was originally equipped for 10,000,000 with two extra filter units provided, which have since been equipped, making the capacity of the plant at the present time 12,500,000 gallons a day. The plant is located upon the hill back of the pumping station at a distance of about one mile, and at a total elevation of about 620 feet above the river. The water is delivered into two sedimentation basins of a capacity of about 1,500,000 gallons each. Coagulant is added as water enters the basins, and more coagulant may be added at the baffle wall half way across the basin, or as the water flows from the basin to go to the filter beds. Hypochlorite of lime may be added at the baffle wall or at this last point. As the water from the cribs is very low

in turbidity, it has been found advisable to add some raw river water. This gives softer water, and the small amount of turbidity thus added aids sedimentation.

This plant was put into operation in July, 1910. During July and August the gauges, controllers, etc., were tested and regulated, but it was not until September that regular records were kept. Hypochlorite was not added until November, and has been used regularly since that time. A comparison of the results with those obtained at the Pittsburgh plant is interesting. The average number of bacteria per cubic centimeter in the water as it entered the sedimentation basins for the last four months of 1910 was 5200, ranging from a monthly average of 350 in September to 14,130 in December. The average number of bacteria per cubic centimeter in the filtered water for the four months was 78, with monthly averages ranging from 15 in September to 114 in December, with maximum counts of about 250. The colon bacillus was found in 10 out of 21 samples of raw water, and in only 2 out of 289 samples of the filtered water. Alum used averaged 0.82 of a grain per gallon, and the hypochlorite 0.036 of a grain per gallon.

For the year 1911, the average number of bacteria per cubic centimeter in what few river samples were examined was 16,870, and in the water as it entered the sedimentation basin 4718. In the filtered water the average for the year was 14, with monthly averages ranging from 62 in January to 3 in July. Colon bacillus was found in 661 samples out of 771 of the water as it came to the sedimentation basins, and in 17 out of 1047 samples of the filtered water examined. The average coagulant for the year was 0.92 of a grain per gallon, and the hypochlorite 0.041 of a grain per gallon. The average amount of water pumped per month was a little over 250,000,000 gallons.

For the year 1912 the results were about the same as for 1911.

During the first two years of operation it was, of course, necessary to experiment, in order to determine the most efficient method of operating the plant. The improvement is shown by the detailed figures which follow for the operation of the plant for 1913:

DATE	HYPO. CALCIUM, GRAINS PER GALLON	SULPHATE OF ALUMINA, GRAINS PER GALLON	PER CENT WASH WATER USED	PARTS PER MILLION, TURBIDITY				PARTS PER MILLION, COLOR				BACTERIA PER CUBIC CENTIMETER						GALLONS DELIVERED PER MONTH
				Average		Highest day		Average		Highest day		Average			Highest day			
1913				Mixed	Filt.	Mixed	Filt.	Mixed	Filt.	Mixed	Filt.	River	Mixed	Filt.	River	Mixed	Filt.	
Jan.	0.061	0.97	2.4	59.4	0	150	0	29.6	0	45	0	5,756	3,305	4	14,350	10,350	22	255,690,863
Feb.	0.058	0.95	2.3	16.4	0	150	0	17.2	0	35	0	2,779	1,317	6	5,800	3,100	15	240,743,223
Mch.	0.061	1.00	2.5	38.5	0	150	0	27.5	0	45	0	4,500	2,379	3	12,000	7,000	7	262,342,093
Apr.	0.056	0.86	2.2	5.4	0	10	0	17.5	0	23	0	2,523	1,078	2	6,300	3,750	4	260,978,518
May	0.057	0.83	2.1	7.8	0	40	0	21.6	0	35	0	9,692	4,719	3	31,000	22,780	10	280,862,782
June	0.058	0.85	2.2	27.4	0	400	0	22.9	slight	40	slight	17,773	13,943	3	45,000	36,500	8	277,832,302
July	0.064	1.03	2.2	41.1	0	300	0	33.9	slight	45	slight	15,531	9,537	6	30,500	23,000	20	287,026,221
Aug.	0.060	0.93	2.1	10.6	0	60	0	23.9	0	40	0	17,213	12,319	3	31,500	25,000	6	297,387,037
Sept.	0.062	0.99	2.3	9.6	0	35	0	26.5	0	42	0	22,371	17,175	4	45,000	38,500	15	269,650,365
Oct.	0.062	1.04	2.3	17.5	0	60	0	29.2	0	50	0	12,428	9,926	3	33,000	31,500	7	270,310,052
Nov.	0.060	0.98	2.4	18.6	0	125	0	24.6	slight	48	0	4,117	1,938	1	19,300	12,500	3	250,492,179
Dec.	0.050	0.70	2.0	2.6	0	10	0	14.4	0	25	0	984	561	3	1,600	1,900	9	249,716,454
Average	0.059	0.93	2.3	21.2	0			24.1	0			9,639	6,533	3.4				

During the year 1913 the colon bacillus was found in 473 out of 531 samples of the river water examined, and in 784 out of 1065 samples of the water as it entered the sedimentation basins. It was found in 2 out of 1062 samples of the filter water and in none of 1038 samples of tap water which were examined.

J. N. CHESTER: The speaker always feels grateful to any one who will prepare and arrange such tables and such a volume of statistics accompanied by intelligent comments as Mr. Johnson has furnished in this paper. If, however, in the compilation of this, the attitude has been assumed that there is a conflict between slow sand filters and rapid sand filters and the cudgel has been taken up on either side by the writer, the speaker is not in accord with his attitude. It is the speaker's belief that every situation presents its own problems, which the engineers of this country are able to solve, and that the information we have in this paper will assist greatly in the solution of such problems.

The speaker is very glad that Mr. Gregory has furnished additional data and that he has corrected such statements as he feels are erroneous. Cities are differently situated; they have different waters to handle; and with Mr. Gregory the speaker agrees that a rapid sand filter is much more flexible and therefore adaptable to a much larger number of situations than is a slow sand filter. The cost of rapid sand filters as given by Mr. Gregory for average results, are more in accord with the speaker's experience on the larger and better built plants than the figures that appear in the paper. Of course slow and rapid sand filters have in many instances been built at as low as $10,000 per million gallons capacity, and may be found lower than that; but when you analyze the elements that have entered into those plants, the reason is plain. We always feel when we give an estimate of less than $15,000 per million gallons that we must cut something out to do it, especially if we are going to build a larger sized plant, which ordinarily costs more than a small plant per million gallons, because the large plants have more frills, they have more to cater to from the side of ethics and civics and other things of that sort. When, fifteen years ago, we were building mechanical filter plants we thought of nothing but the tub and the clear water basin, and that was generally very small. Then we talked about building them at a cost of from $8,000 to $10,000 per million gallons. Later we got to storing larger quan-

tities of clear water and acknowledged the necessity of sedimentation basins. Probably all of you remember when we built without sedimentation basins; and now we are building more expensive filters using concrete instead of steel or wood; and thus the cost of the mechanical filters has been going up instead of down.

The speaker will not attempt to take up the cudgel for either slow sand or mechanical filters. The matter of location and land has been pretty thoroughly discussed by Mr. Gregory, and the speaker heartily concurs in his statement that they are governed by circumstances and may be one thing in one place and another thing in another place.

There are, however, some things in this paper to comment on here that do not relate to the cost but to other matters. It has been pretty well admitted that slow sand filters are not adaptable to extremely turbid water; and when the selection of slow sand filters was made in Pittsburgh, it was considered that Pittsburgh was just about on the edge of the zone of turbidity that would permit slow sand filters; and, as has been the case in other instances, it was found afterward that the preliminary tests and determinations that were made prior to the building of that filter did not reveal subsequent high peaks, although they got high peaks that year. And, of course, you know the outcome is that other arrangements have been made to keep down those peaks. The statement that we have 2000 p.p.m. more turbidity there is correct; but even those turbidities are small as compared with rivers further west. Mr. Montfort could testify to some higher turbidities they have in his neighborhood. At Kansas City, St. Joseph, and other points along the Missouri River you will find what sedimentation basins must do, and then if you reflect a few minutes you will find that the design of the plants in those neighborhoods should be somewhat different from the design of the plant in Pittsburgh where the turbidities are but 2000 and below instead of 10,000 and sometimes above as in the case of the western waters.

The comments on the use of lime, or the necessity of using lime, to prevent the CO_2 and consequent red waters, is underestimated by the author, at least in some districts. In our Pittsburgh districts at least, and in many others, there are periods of the year when the addition of lime even though the alkalinity does not require it, is an absolute necessity to prevent excessive CO_2 in the water and consequent red water results. These are annual occurrences, and not occasional ones in the Pittsburgh district, but they are occasional in many other districts.

Mr. James M. Caird: The writer regrets that he was unable to be present when this valuable paper was presented. The paper treats with great detail the progress made in this country in the art of water purification. It would be interesting to know exactly what is being done abroad, and if slow sand filtration is as popular as formerly, or if there has been a change to the American or mechanical filters.

There has been very little advancement in the constructive features of slow sand filters in this country. The improvements have been chiefly in the method of removing and washing the sand. At Wilmington, Delaware, the sand is washed in the beds, and up to the present time this method has been a success at this plant.

At the present time there are few slow sand filters in this country where the method of operation has not been changed. The changes consist of larger settling basins, pre-filters, coagulation and sterilization.

In the colder climates the slow sand filters are very difficult to operate owing to the formation of ice on the beds; this of course requires a greater construction as well as operating cost.

It is true that the bacterial efficiencies decrease during the colder months, but the most trouble is with the slow sand filters which become readily, "air bound."

In this country there are about 480 filtration plants with a combined capacity of 2,565,000,000 gallons daily, 450 or 93.7 per cent are of the American or mechanical type and furnish 1,745,000,000 gallons or 68 per cent of the filtered water.

Originally the great difference between the two methods of filtration was the use of a higher rate and coagulants by the American or mechanical filters. At the present time about all the slow sand filters are using coagulants and thereby are able to operate at a higher rate, so that they are following the example of the American method.

Albany having had considerable trouble in operating the slow sand filtration plant, pre-filters have been installed. A sterilizing agent is now in use and if the writer has been correctly informed a coagulant is used for at least part of the time.

At Rensselaer (East Albany) New York, population 11,000, there is a mechanical filter operating on Hudson River water, the same supply as is used at Albany, but on the Troy side of the river and therefore containing more sewage than the Albany unfiltered water.

This plant uses sulphate of alumina as a coagulant and also calcium hypochlorite.

Table showing bacterial efficiency and typhoid fever death rate, per 100,000 population, Rensselaer, N. Y.

YEAR	EFFICIENCY	TYPHOID RATE
	per cent	
1910	98.75	28.0
1911	99.84	18.7
1912	99.96	9.3
1913	99.71	0.0
Average	99.56	14.0
1900–05		67.5

Typhoid fever reduction 79.3 per cent.

The Washington case was most peculiar in that both methods of filtration were tested experimentally, the results showing that the American or mechanical process did the better work, yet in the face of these facts a slow sand filter was installed. At the time great objections were raised against the use of coagulants; however, it has been found that satisfactory results could not be obtained without the use of a coagulant, and this method is now in use in connection with the slow sand filters.

In 1901 there was an inquiry held by the United States Senate Committee on the District of Columbia on the purification of the Washington water supply, at which hearing great stress was laid upon the fact that at Elmira, New York, they used mechanical filters and that there were ten deaths from typhoid fever the year before the filters were installed and eleven deaths the year the plant was placed in operation or an increase of 10 per cent in the death rate.

The first year the Washington plant was in operation there was no great reduction in the typhoid fever death rate and a very extensive investigation was made to learn the cause.

Table showing typhoid fever death rate per 100,000 population at Washington, D. C. and Elmira, N. Y.

YEAR	WASHINGTON	ELMIRA
1907	36.0	28.0
1908	39.0	30.7
1909	33.0	33.5
1910	25.0	26.9
1911	22.0	13.3
1912	23.0	15.9
Average	29.6	24.7

These results show that during the same period the Elmira typhoid fever death rate averaged 16.6 per cent less than that at Washington.

The Elmira situation is rather peculiar in that there are about one thousand wells in use, and the water company is unable to close these wells. The State Board of Health in a recent examination of fifty wells reported that 65 per cent contained B. coli-communis. When the history of a typhoid fever case shows that a patient used water from a certain well, the local board of health have the water examined, and if B. coli-communis is found, the well is closed. The wells are not examined until such time as they fall under suspicion.

The water supply of Elmira is divided as follows: 25,000 using filtered water, 5000 using well water and 5000 using a mixture.

The Elmira typhoid fever death rate for the year 1913 was 10.5 per 100,000 population. During the six years 1907–12 there was a total of fifty-three deaths in Elmira from typhoid, seven or 13.2 per cent claimed to have used nothing but well water, while twenty or 37.7 per cent of the deaths, were among cases imported to the local hospitals.

The average number of bacteria in the Washington filtrate was 54 per cubic centimeter, while the Elmira average was 40 per cubic centimeter or 26 per cent less. The Elmira unfiltered water contained 10,907 bacteria per cubic centimeter while the Washington contained 1930 per cubic centimeter, or 82.4 per cent less. During the past year the Elmira filtered water contained an average of nine bacteria per cubic centimeter.

There is no statement in Mr. Johnson's paper as to the media used for the bacterial work. At all plants with which the speaker is connected, the efficiency of the plants is based upon the bacterial growth on gelatin for forty-eight hours as 20°C.

If there ever were two places where American or mechanical filtration should have been installed they are Philadelphia and Pittsburgh. The Pennsylvania Water Company, Wilkinsburg, Pennsylvania, supplies several of the suburbs of Pittsburgh. American or mechanical filters are used, the supply being obtained from filter cribs in the Allegheny River and also river water direct. This water is thoroughly aerated, sulphate of alumina being added before aeration, after which the water passes through a coagulation basin and calcium hypochlorite is added to the water before it enters the filters.

Table showing results, Wilkinsburg, Pa.

YEAR	BACTERIA PER CC.		REMOVAL	CHEMICALS	
	Raw	Filtered		Alumina	Hypo
			per cent		
1911	4,051	36	99.12	0.93	0.035
1912	7,953	31	99.62	0.92	0.044
1913	6,266	4	99.64	0.92	0.058
Average....	6,090	24	99.61	0.92	0.046

The filtered water is always free from color and turbidity, aeration and coagulation removing the iron.

The Baltimore County Water and Electric Company, Baltimore, Maryland, operate a slow sand and also mechanical filters on the same water at their plants located at Avalon, Maryland. As far as the writer knows, this is the only place in this country where the same unfiltered water is used for both style filters.

The American filters remove practically all of the color and turbidity, which is not the case with the English filters.

Average results four years, 1908–11, Avalon, Md.

BACTERIA PER CC.			B. COLI 1 CC. SAMPLES		
Raw	Eng. Filtration	Am. Filtration	Raw	Eng. Filtration	Am. Filtration
			per cent	per cent	per cent
2,662	38	24	63.6	3.12	1.72

From reading Mr. Johnson's paper, one would be led to believe that there never had been any trouble with any filters of the American or mechanical type. During the past few years there have been some changes in the type of strainer systems, and the speaker knows of three plants where the new strainer system has given out within a short time after being placed in operation, and where trouble has been experienced in getting a uniform washing of the beds. It is the speaker's opinion, that the old method of strainer heads is to be preferred to the use of the wire screens placed over the gravel.

There is no question but that the American or mechanical filters are able to treat any water which can be treated with slow sand filters, and that mechanical filters can treat water which cannot be treated by slow sand filters.

Sulphate of alumina is the best coagulant, and can be used for all waters. Sulphate of iron and lime do not give good results with a water containing high vegetable colors.

Mention is made of the socalled "red water plague" and that it is thought to be more pronounced where sulphate of alumina is used as a coagulant. The amount of sulphate of alumina used as a coagulant has been greatly reduced since the hypochlorite process has come into use. The use of calcium hypochlorite tends to still further reduce the amount of free carbonic acid in the water and hence any action from this cause is reduced. The speaker has had great success from the use of hydrated lime in absorbing carbonic acid, and it is also of great value in making up the deficiency in alkalinity.

No matter which type of filter is in use, it must have proper care or its operation will be a failure.

Mr. J. W. Ellms (*by letter*): Mr. Johnson has clearly set forth in this paper the development of the art of water filtration, and the important position which it holds in the field of general sanitation. He presents statistics of a convincing character, showing the greater adaptability of the system of rapid sand filtration to the waters of the United States, than that of slow sand filtration. With his views on this matter the writer is in entire accord, and believes that no other logical conclusion than that stated by the author can be drawn from the facts.

The effect upon the health of a community of the substitution of a filtered water supply for one that had been used unfiltered, and which was known to be badly polluted, is no more strikingly shown than in the case of the city of Cincinnati, where filtered Ohio River water was introduced in the latter part of 1907 in place of the raw river water. The writer has compiled some mortality statistics for a period of six years before and after the introduction of filtered water, and believes they may be of interest in connection with this paper.

The accompanying table (marked table 1) gives in detail the actual number of deaths, and the rate per hundred thousand of population for a number of the more common diseases, and for all causes, for a period of thirteen years. Some of the specific diseases listed are probably in part water-borne, such as typhoid fever, diarrhoea, enteritis and dysentery; others may be so disseminated, while some of them are probably not transmitted by water at all. As the year 1907 was one in which unpurified Ohio River water, both from the

TABLE I

Number of deaths and rate per 100,000 of population in Cincinnati, Ohio, from all causes and for certain specified diseases before and after the introduction of a filtered water supply

UNFILTERED WATER

	1901		1902		1903		1904		1905		1906		1907	
	Total Deaths	Rate per 100,000	Total Deaths	Rate per 100,000	Total Deaths	Rate per 100,000	Total Deaths	Rate per 100,000	Total Deaths	Rate per 100,000	Total Deaths	Rate per 100,000	Total Deaths	Rate per 100,000
Typhoid Fever	182	55.3	206	62.1	150	44.7	270	78.0	155	44.4	239	67.9	157	44.4
Diarrhea and Enteritis	359	109.1	173	52.1	386	114.9	506	146.3	528	151.3	516	146.6	279	78.6
Dysentery	49	14.9	29	8.7	24	7.1	27	7.8	21	6.0	22	6.3	30	8.4
Pneumonia	456	138.6	425	128.0	440	131.0	631	182.4	594	170.2	505	143.6	419	118.0
Tuberculosis Lungs and Larynx	755	229.5	675	201.7	804	239.3	920	266.0	900	258.0	920	261.3	858	241.8
Diphtheria and Croup	69	21.0	78	23.5	63	18.7	38	11.0	78	22.4	77	21.9	56	15.8
Whooping Cough	17	5.2	14	4.2	16	4.8	4	1.2	44	12.6	11	3.1	15	4.2
Scarlet Fevers	24	7.3	51	15.4	37	11.0	26	7.5	73	20.9	10	2.8	5	1.4
Measle	45	13.7	33	9.9	19	5.7	37	10.7	5	·1.4	61	17.3	19	5.4
All causes	6155	1871.0	5744	1730.0	6201	1845.0	7038	2034.0	6534	1872.0	7195	2044.0	6414	1807.0

FILTERED WATER

	1908		1909		1910		1911		1912		1913	
	Total Deaths	Rate per 100,000	Total Deaths	Rate per 100,000	Total Deaths	Rate per 100,000	Total Deaths	Rate per 100,000	Total Deaths	Rate per 100,000	Total Deaths	Rate per 100,000
Typhoid Fever	64	17.9	46	12.8	21	5.8	43	11.4	28	7.3	24	6.0
Diarrhea and Enteritis	419	117.1	378	104.8	449	123.5	365	96.6	334	86.2	321	80.6
Dysentery	9	2.5	11	3.2	5	1.4	7	1.9	11	2.8	11	2.8
Pneumonia	423	118.2	382	105.8	388	106.6	288	76.2	303	78.3	609	153.0
Tuberculosis Lungs and Larynx	869	242.8	860	238.2	912	250.5	876	231.7	856	221.0	889	223.2
Diphtheria and Croup	54	15.1	38	10.5	28	7.7	48	12.7	60	15.5	53	13.3
Whooping Cough	28	7.8	21	5.8	24	6.6	16	4.2	27	7.0	50	12.6
Scarlet Fevers	31	8.7	14	3.9	13	3.6	71	18.8	38	9.8	20	5.0
Measle	53	14.8	2	.6	65	17.8	10	2.6	34	8.8	67	16.8
All causes	6449	1801.0	5921	1640.0	6330	1739.0	6225	1649.0	6453	1663.0	6734	1691.0

TABLE 2

Average death rates per 100,000 of population, Cincinnati, Ohio, and the percentage increase or decrease from certain specified diseases, and from all causes for periods between 1901 and 1906, both inclusive, and 1908 and 1913, both inclusive.

	Rate		Average percentage	
	1901–1906 Unfiltered water	1908–1913 Filtered water	Increase	Decrease
Typhoid fever	58.7	10.2		82.6
Diarrhoea and enteritis	120.0	101.5		18.5
Dysentery	8.5	2.4		71.8
Pneumonia	149.0	106.4		28.6
Tuberculosis (lungs and larynx)	242.6	234.6		3.3
Diphtheria	19.8	12.5		36.9
Whooping cough	5.2	7.3	40.4	
Scarlet fever	10.8	8.3		23.1
Measles	9.8	10.2	4.1	
All causes	1899.3	1697.2		10.6

old and the new water works' intakes, was supplied to the city, as well as filtered water during the last two months of the year, it may be omitted when making a strict comparison of death rates for the two periods.

The reductions in the death rates in the filtered water six-year period, 1908–1913, from those in the unpurified water six-year period 1901–1906, are given in the accompanying condensed table (see table 2). In each disease, except whooping cough and measles, there has been a reduction in the rate, ranging from 3.3 per cent to 82.6 per cent, these diseases being tuberculosis of the lungs and larynx, and typhoid fever, respectively. For all causes of death there has been a reduction of 10.6 per cent. In typhoid fever the reduction has been most marked, with dysentery next in order of the diseases listed. Increases in the rates are shown only in the case of whooping cough and measles. The net reduction in the death rate for the group of diseases listed which constitute 32.9 per cent of all the causes for deaths in the first period, is practically 21 per cent. The reduction in deaths from this group of diseases had the effect of lowering the death rate from all causes by 6.9 per cent. Since the net reduction in the rate from all causes is 10.6 per cent, it is evident that about two-thirds of the reduction resulted from fewer deaths from the diseases listed in this group.

While there is no doubt that water-borne diseases have tended during the past six or seven years to reduce the total death rate in Cincinnati, other sanitary improvements have also played an important part. The education of the public in matters of sanitation must eventually have an effect upon the death rate from disease; but this effect is bound to be gradual and would fail to show the marked reduction in the rate exhibited in Cincinnati following the first year of use of filtered water. The conclusion that a purified water supply has reduced the total death rate in Cincinnati seems to be reasonable.

MR. GEORGE W. FULLER (*by letter*): Mr. Johnson's interesting and instructive paper points to a conclusion with which the writer is in general accord, namely, that sand filters are less satisfactory for the vast majority of water purification projects in the United States than is mechanical filtration. The former have been pushed into fields where their accomplishments have developed well-defined shortcomings in point of efficiency or economy or both.

In making the above statement it is to be clearly recognized that there are some exceptions to all rules, and in this regard the legitimate scope of sand filters probably has a field, limited as it is, from which other forms of water purification are not likely to drive them out. Nevertheless as the field of water purification has broadened so as to include the muddy water supplies from surface streams the applicability of mechanical filters has asserted itself more and more strongly. For those supplies requiring coagulant in order to bring about satisfactory purification, there is no room for doubt as to the superiority of mechanical filters under all ordinary circumstances.

Twenty years ago sand filters were used in treating a few fairly clear waters along the Atlantic seaboard. Then all water works men were timid and most engineers were afraid to advise filtration for the heavily clayladen waters of the South and Middle West. This was the time when the Providence filter tests to decolorize the local water were under way, and when the late Mr. Hermany was projecting his elaborate tests for demonstrating the practicability of mechanical filters in purifying the muddy Ohio River water. For several years water purification accomplishments were confined largely to exhaustive scientific tests into the merits and demerits of different types and arrangements. Mechanical filters prior to that time had had considerable ingenuity displayed in their design from the standpoint of mechanical arrangement, but hygienically,

their standing was predicated on careful tests at Providence, Louisville, Pittsburgh, Cincinnati and elsewhere.

When the choice of the type of filter arose at Washington, there was a great agitation on the part of the local medical profession against the use of coagulating chemicals and against the hygienic efficiency of mechanical filters based on their accomplishments in practice. So far as scientific studies carefully conducted on the two types of filters were concerned, there was no room then for deciding that either type possessed any decided advantage over the other. Each would be satisfactory. But when it came to rating the standing of the two types of filters upon the basis of the influence which plants of each kind had produced upon the death rate of cities where they had been installed, both European and American evidence gave the advantage to sand filters.

The splendid record of achievement by mechanical filters during the past dozen years or more changes that evidence materially, in that the accomplishments in reducing the death rates in the case of mechanical filters compare most creditably with corresponding data upon sand filters. That is, the mechanical filter has emerged from the test-filter-and-laboratory-demonstration style of evidence upon which to rest its credibility, and it stands today on its record of successful service as the prevailing type of filter in the United States in the treatment of water supplies when due regard is given both to efficiency and economy.

To the writer's thought, the two types of filters are entitled to equal standing in point of efficiency when each filter is properly built and operated, as should always be the case.

Some may find fault with Mr. Johnson's conclusion as to the comparative hygienic efficiency as shown by typhoid fever death rates in communities served by the two types of filters. The basis of this would be, of course, that the two types of filters do not necessarily deal with the same type of raw water and that the water consumers in the different cities are not subjected to the same general sanitary conditions, some of which, rather than the quality of the public water supply, are substantial factors in explaining the prevalence of typhoid fever.

In some measure a similar criticism might be made as to the relative costs of filtration in different places, where there are known to be differences in the costs of labor and materials and in other local conditions affecting cost. Whether construction costs represent fair profits to the builder, which should always be the case, is another point which should not be taken for granted.

However, considering the whole story along broad lines, as is the obvious intent of the author, there seems to be no sound basis for taking serious exception to his conclusions, which essentially are "that in the efficient and economical solution of the vast majority of water purification problems in the United States, the rapid sand filtration process is superior to the slow sand process."

MR. CHARLES B. BUERGER (*by letter*): The selection of the type of filter most suitable to any particular water, under such conditions that neither slow sand nor rapid sand is immediately ruled out by obvious considerations, forms, for each locality, a problem in itself; sometimes this is a difficult, sometimes an easy one to decide. Generalizations drawn from a number of plants must be taken with much caution, as the differences of conditions, design, local high or low costs of construction and operation, make comparisons difficult. Averages are still more unreliable.

We find on page 69 of Mr. Johnson's paper a table of first costs. These are no doubt representative, but there are many well-known plants running away from these averages. Among them may be mentioned:

Slow sand plants, double filtration	*per mgd.*
Queen Lane, Philadelphia, Pa. (75 mgd.)	$25,000
Montreal, P. Q., Canada (60 mgd. Under construction)	25,000
New York, N. Y. (320 mgd. Projected)	38,000
Rapid sand plants	
Steubenville, Ohio (6 mgd. Under construction)	22,000
Evanston, Ill. (12 mgd. Under construction)	17,000
Jackson, Miss. (4 mgd. Under construction)	17,000
Niagara Falls, N. Y. (16 mgd.)	16,000
New Orleans, La. (Carrolton plant. 40 mgd.)	40,000
Toledo, Ohio (34 mgd.)	17,000
Flint, Mich. (8 mgd.)	18,000
New York, N. Y. (320 mgd. Projected)	23,000

While the Cincinnati cost for a rapid sand filter may for any particular projected work be a better guide than the New Orleans cost, it is equally true that the Queen Lane or the Montreal cost may be a better guide than the Torresdale. Operating costs, too, must be considered with reference to the local conditions. For instance, the 1911–12 cost per million gallons of $4.01 at Washington, D. C., includes a pumping station cost of $1.24, leaving only $2.77 for the cost of filtration proper.

While emphasizing the needs of special consideration for any new case, the writer feels compelled to endorse Mr. Johnson's conclusion

that the usual proper decision will be in favor of rapid sand filtration. And particularly it should be recorded that even where the total annual charges, including capital and operating costs, are slightly less for a slow sand plant without chemical treatment, a proper business judgment will lead to a reservation of the excess investment. A higher cost of construction is not justified if it saves alone its interest in later operation charges; there must be a recognition of the removal of this useful capital from other fields of service and its potential earning power or service value in these other fields.

Mr. Johnson's reference to the difficulties which have been experienced with the Philadelphia Torresdale filters brings up a feature worthy of comment. The Torresdale preliminary filters were the first of their type, and there was no precedent to indicate, except in a general way, what their design should be. The successful Little Falls filter was based on fifteen years of indifferently successful trial with filters of the same principle, and after most elaborate scientific studies at Louisville and Cincinnati. A scrubber or preliminary filter designed in 1902, after fifteen years of use of preliminary filters, may show markedly improved results.

The differences between this Torresdale design of 1907 and the Montreal design of 1910 indicate possible lines on which better results might be obtained.

	TORRESDALE	MONTREAL
Maximum filter head	4.5 feet	12 feet
Thickness sand bed	12 inches	30 inches
Size sand (effective)	0.8 to 0.9 mm.	0.5 to 0.6 mm.

A limiting feature in the design of the Torresdale preliminary filters arose out of a peculiar local situation. Mr. Fred C. Dunlap, in 1907, chief of the Bureau of Water, and designer of this plant, found that his predecessor had purchased the raw water pumps without any intention of building or making any provision for these preliminary filters. He was working on the assumption that he could install water meters and cut in half the necessary water supply. The available pump head was thus 5 feet less than originally contemplated, and the filters were then designed to squeeze within this insufficient head. Much of the weakness of this plant may be attributed to a political rather than an engineering cause.

After all has been said, however, a vote by engineers who have worked on this plant as to proper treatment for this Delaware water, would be unanimously in favor of coagulation. The combination

of occasional coagulation with the present equipment may eventually be found to make a highly satisfactory plant, even on the basis of total annual charges.

Mr. Theodore A. Leisen: It seems to the speaker that the fullest possible discussion of this paper would be highly advantageous to the Association, and particularly along this question of comparative costs. Mr. Gregory has very ably discussed it and has given us a great deal of additional information. It is hoped there will be further discussion, whether written or otherwise. The matter of costs of filter construction is open to the same line of error that was referred to the other day in connection with comparison of rates of different cities. There are so many elements entering into the thing that it is very difficult to avoid being misled unless all of the various factors are thoroughly understood. For instance, the original Louisville filter, if we eliminate the pumping stations and some other elements that might strictly be considered part of the filter plant, would stand at roughly speaking about $20,000 per million gallons, and possibly over that. That is somewhat higher than any of the others mentioned here, it includes a larger clear water basin than the average. There is a recent addition to filters now nearing completion. But if the cost were given offhand without understanding the matter it would stand at about $5000 per million gallons; so that any comparison without having the thing thoroughly understood would be misleading.

Regarding the turbidities, our record of the year is not here; but our turbidities at Louisville went up as high as 6000 p.p.m. last year, while 1000 is quite a common occurrence; and those waters could not be dealt with with a slow sand filter. In that case a mechanical filter is absolutely necessary.

It is unfortunate that, in so many of the discussions as to types of filter, too much prejudice seems to get into the question on the part of a number of people who have taken the thing up in recent years. There is a field for both the slow sand filter and the mechanical filter, and it is purely a question of judgment in each particular instance as to which one is to be used; but the matter ought to be discussed without any passion or prejudice whatever. Mr. Gregory's discussion brought that out and showed that he was looking at it from a purely fair-minded point of view.

Mr. Robert Spurr Weston: The speaker read over Mr. Johnson's paper with a great deal of interest, and the considerable time

required was well spent. Mr. Johnson has approached the subject from the standpoint of twenty years' experience, and has collected a vast amount of data which will be invaluable to water works operators and constructors from now on. The first reading of the paper left the impression of an argument in favor of mechanical filters; also the impression that the field in which the slow sand filter is operable is being rapidly diminished, and ultimately slow sand filters will disappear from use and mechanical filters will take their places. In other words, sand filters will pass out of use just as have Cornish engines.

Now, much as the speaker commends Mr. Johnson's paper, he cannot avoid discussing the other side of the question, and hopes that he has had broad enough training and experience, and sufficient acquaintance with all phases of the water purification problem, to be considered a practitioner in the field of water purification, rather than a partisan in favor of one of the two types of filters mentioned.

Each locality has its problem and should attempt its own peculiar solution. Undoubtedly, many slow filters were built and installed where rapid filters should have been chosen. Pittsburgh and Washing, D. C., are cases in point, and which have occurred in the writer's practice, but there are other cases where slow filters are not only more economical but more efficient than mechanical filters, and some of these cases are where high rates of filtration may be employed without detriment, because it is obvious that the cost of slow filters per million gallons decreases rapidly and inversely with the rate of filtration.

Generally speaking most engineers who are competent in the field of water purification, that is, those who have studied the problem for a long time in connection with many types of waters, are agreed that mechanical filters are best where the color is over 50 parts and the turbidity over 30 parts per million, or where there are unusual fluctuations in the character of a stream, which ordinarily is but slightly colored or turbid. Again, there are other cases where the water is so clear that there are no nuclei to start the coagulation of the applied chemical, upon which coagulation the efficiency of mechanical filters depends. To use mechanical filters in these cases may necessitate the addition of clay or other suspended matter to produce an artificial turbidity, or the use of an excessive amount of coagulant, so that the coagulant will precipitate by virtue of its large mass.

Before this paper was written the speaker made some studies of the comparative costs of slow sand and mechanical filters for presentation at a town meeting, and came to the conclusion that an

average cost of $14,500 per million gallons for mechanical filters, and a cost of $100,000 per acre for slow sand filters were good average figures. These figures are higher in the case of mechanical filters and lower in the case of slow sand filters than given by Mr. Johnson. In Mr. George W. Fuller's report on the Montreal Water Supply, dated July 22, 1910, the cost of sand filters was estimated at $33,840 and mechanical filters $21,091 per million imperial gallons daily capacity. The cost of slow sand filters per million gallons varies with the rate as the following table, assuming covered filters and appurtenances to cost $100,000 per acre, shows.

Rate of filtration mgd.	*Cost per mgd.*
10	$10,000
6	16,667
5	20,000
4	25,000
3	33,333
2.5	40,000

The cost of mechanical plants generally varies with the character of the water, and the writer believes the estimates in the following table represent the best practice in plants of moderate size. The costs include the necessary subsiding and coagulating basins; also small filtered water basin or pump-well.

Character of water	*Cost per mgd.*
Turbidity or color	
0 – 100 or 0 – 25	$14,000
100 – 300 or 25 – 75	16,500
300 upwards or 75 upwards	18,500

The above costs are higher than those of the largest and best plants constructed under favorable conditions, but lower than those of plants where unusual conditions prevail.

A mechanical and a slow sand filter, each of 1,000,000 gallons daily capacity, designed and constructed under the speaker's supervision during 1913, cost $16,000 for the mechanical and $18,000 for the slow sand plant. The cost of engineering for the mechanical filter was unusually high and the slow sand filter was in connection with a deferrization plant, where the costs included a coke trickler, 15 feet high and 30 feet in diameter, and where the filter operated at 10,000,000 gallons daily rate.

In the paper under discussion many references have been made to the hygienic efficiencies of plants treating waters which have been

disinfected with chlorine, and in many cases these have been compared with waters which have not been so treated. The cost of sand filtration depends upon the rate. In the early days, as will be remembered, slow filters were designed at rates of 2,650,000 gallons per acre per diem, and less, this rate being the German official rate of 100 vertical millimeters per hour. If bleaching powder be used to sterilize the effluent, there is no reason why this rate cannot be raised much higher than 6,000,000 gallons per acre, which is the maximum in ordinary present day practice.

Apart from the cost and efficiency factors in some cases, the speaker is in hearty agreement with the conclusions of Mr. Johnson's paper, namely that the mechanical filter is an efficient and reliable sanitary machine, one that will reduce the death rate due to water-borne diseases. It is true that the zone in which slow filters are used is narrowing, while that in which mechanical filters are used is broadening, but the speaker still contends that there is still a field for the slow filter, namely, where clear waters have to be purified and where local conditions make the cost of water furnished by the slow filter less. In comparing the efficiency and economy of the two types, one should use the same basis. One should not compare the efficiency of filters where the effluent is sterilized with those where no sterilizing chemicals are used.

Mr. James W. Armstrong: Some of the speakers in making their comparisons have given the cost of mechanical filter plants at prices from $15,000 to $20,000 per million gallons, and one of them suggested that in future the cost would probably be increased rather than decreased. The speaker does not believe that the added refinements which seem necessary in the larger plants need materially increase their cost per million gallons. With the proper design and arrangement of the various parts, a saving can be made in large plants which will more than offset the added cost of mechanical devices, as they are generally small in comparison with the total cost of the plant.

The filter plant now being constructed for the city of Baltimore is to be equipped with all kinds of operating and regulating devices, and its total cost, exclusive of real estate and legal expenses, will be about $1,400,000 which is a little over $10,900 per million gallons, For the sake of comparison with other filter plants, the speaker would like to state that the Baltimore plant has 32 filter units, having a combined normal capacity of 128,000,000 gallons, supported

by groined arches above filtered water basins having a capacity of about 2,500,000 gallons, a mixing chamber of nearly half an hour's capacity, two coagulating basins with a combined capacity of three hours, two covered filtered water reservoirs with a combined capacity of about 15,000,000 gallons, a head house containing a completely equipped laboratory, and a complete mechanical equipment, an intake shaft and pumping station, containing electrically operated centrifugal pumps having an aggregate capacity of 160,000,000 gallons, two earth dams, one of which is to be faced with concrete for forming the storage basin for the wash water, and two larger concrete wash water tanks. The entire filters are to be covered with a building. The superstructures of all buildings, including the gate houses, eight in number, are to be built of brick laid in cement mortar and covered with green tile roofs.

MR. JOHN C. TRAUTWINE, JR.: The speaker draws some personal satisfaction from Mr. Johnson's paper, which implies that slow sand filtration may not, after all, be the Alpha and Omega of the art, and particularly from his figure 2, which shows that there are, at present, about 12,000,000 persons supplied with filtered water in the United States, whereas, in 1899, not much more than about one-tenth of that number were so supplied. The paper (and especially its fig. 2), seems to give him the melancholy satisfaction of saying: "I told you so."

During the speaker's chiefship of the Philadelphia Bureau of Water (1895–99), there was no filtration of the Philadelphia water; and the City Fathers refused all appropriations for extensions and improvements. The Delaware water was polluted by the city's own sewage, and the Schuylkill water by the drainage from a densely populated mining and agricultural district with numerous cities and towns. After every rain, the Schuylkill water, for the first few days, was little better than liquid mud; and this was succeeded, a day or two later, by coal dust from the anthracite regions, making a tumblerful of Schuylkill water look like a tumblerful of ink.

Filtration was actively discussed, but there was no thought of giving us the benefit of expert advice. Rapid (so-called "mechanical") filtration was well to the fore, disputing the supremacy of the orthodox slow sand filtration, which was disputed also by numerous other filtration devices.

Recognizing his inability to decide off-hand between the claims of these several systems, especially in view of the fact that each

city and each river furnishes a problem of its own, the speaker urged that two of the smallest of our six stations, one on each of our two rivers, be made a practical experimental filter plant, composed of units representing the several approved systems of the day, and furnishing water, not merely for experiment, but for the actual supply of the districts served. This would not only have demonstrated the advantages of filtration as applied to our water, and improved the supply to the districts served, but would also have enabled us to decide between the claims of the conflicting systems. This, however, was far too "scientific" a procedure for the City Fathers, who, in response, demanded plans and estimates for filtration plants sufficient for the entire city.

With our engineering force consisting of three draftsmen, and one chief draftsman, the speaker set about responding to this demand, submitting plans involving the general adoption of slow sand filtration; but (still recognizing the need of further light upon the subject) provided for a rapid filtration plant in connection with one of the stations, viz., that at Queen Lane; and in this respect, he was followed by the experts of 1899, Messrs. Rudolph Hering, Samuel M. Gray and Joseph M. Wilson, who, in their plans, provided for a rapid filtration plant in connection with the Spring Garden or East Park System.

But, when the final decision was made, the new administration, in whose behalf all appropriations had been held up, decided peremptorily against the consideration of the rapid filtration system; and the city thereupon proceeded to the construction of its present $30,000,000 plant, composed, at first, entirely of slow sand filtration beds; but, these proving inadequate to the demand, were later supplemented by preliminary filters.

Mr. Johnson's figure 2 confirms the speaker's statement, made to the city councils during his chiefship, that the science and art of filtration were then in their infancy, and shows that the present tendency is to the increased use of rapid filtration. It thus indicates that it might have been well for us to take a little more time to make sure that we were right, before going ahead.

The refusal (already mentioned) of the city councils to appropriate money for extensions during the speaker's administration, and the open boast of local patriots that the appropriations were being deliberately held up in favor of the succeeding administration, led him to suspect that the cost of our works (quoted by Mr. Johnson) may have been higher than was absolutely necessary.

Mr. Robert E. Milligan: The speaker has noted one or two matters during the discussion that seemed to him to be in corroboration of his own experience in mechanical filtration. This matter of costs as one may gather from the discussion is one very difficult to accurately define. Frequently the speaker is asked to make an approximate estimate in advance. Some of these inquiries come from engineers themselves for information that can be easily gotten by the manufacturer from the very many filter plants that have been installed in the United States and other parts of the world.

As a matter of fact, the speaker believes that Mr. Chester is in error in saying that large plants are not necessarily less expensive per million gallons than small ones; and Mr. Armstrong has mentioned the fact that Baltimore is an instance of very low cost. In this connection it must be remembered that there are very few cases as yet of mechanical filtration plants of over 25,000,000, or say 50,000,000 gallons, to compare any costs on; but probably the lowest price ever offered for a mechanical filter plant of great size was the recent offer in connection with Jerome Park, New York City, when the difficulties of labor and construction are considered; and this cost actually was approximately $15,000 per million gallons. Such plants as the one at Hackensack and Little Falls, New Jersey, ranging above 30,000,000 gallons capacity, have cost in the neighborhood of $15,000 per million gallons but, since they are very limited in subsidence, if compared are greatly in excess of the Jerome Park costs. Commonly small plants ranging from 1,000,000 to 10,000,000 gallons, or 1,000,000 to 5,000,000 gallons will present very high costs if equipped with the large areas of subsidence common to large filter plants as they generally carry with them machinery which increases the unit price very materially, such as blowers and wash pumps, and this cost is out of all proportion in the very small unit. Plants can be, and have been, designed of great efficiency anywhere from 5,000,000 to 10,000,000 gallons at about $10,000 per million gallons; at least that is the speaker's experience in the matter, and he is satisfied that similarly designed large plants would be considerably less per million gallons.

In connection with Mr. Robert Spurr Weston's statement claiming greater efficiency for slow sand filters over mechanical filters in the removal of iron from ground waters, this is not based on any experience that the speaker is familiar with. As a matter of fact there are very few slow sand plants removing iron from ground water

in the United States; in fact, the speaker knows of none outside of New England; while all through New Jersey, where iron occurs in ground waters, there are many mechanical filtration plants, and in the west there are very notable examples, such as Iowa City and Freeport, Illinois, preferring the gravity type, most of the New Jersey plants being of the pressure type. Nearly all of the iron removal mechanical filtration plants operate too at the rate of about 250,000, 000 gallons per acre a day and it should be borne in mind that while a slow sand filtration plant may successfully remove iron from ground water at the high rate of 10,000,000 gallons per acre, it is equally true that mechanical filter plants in many cases are removing iron satisfactorily at a rate of 250,000,000 gallons per acre.

The speaker would like to say this, too, that in the development of mechanical filtration he believes that the pressure filter is becoming more and more effective. The pressure filter is probably the most abused form of filter that we have; and yet the work it has done, to those who have closely watched its performance, is very remarkable indeed. When the speaker says that it will come into its own, he does so because in these days, when chemicals are used without prejudice, sterilization is being depended upon for purification in the sanitary sense and the filter becomes more and more a clarifying and decoloring proposition, and because of the fact that the larger number of water supplies in the United States are clear waters, that is, waters not carrying turbidity beyond 150 or 200 p.p.m., one can realize that a device so economical and so readily installed as the pressure filter must attract a great deal of attention in this connection when absolute sterilizations can be had after decolorization and clarification by filtration.

In the discussion of Mr. Johnson's paper at the New York Section, a very curious theory, that is curious to the speaker, was advanced, to the effect that, while filtration either slow sand or mechanical had reduced the typhoid rate to an average of above 75 per cent in cities employing it, where mechanical filtration had been installed no corresponding decrease in the total death rate occurred, whereas in the case of slow sand filters there was a notable decrease in both the total and the typhoid death rate. The speaker must confess that he did not feel in a position to contradict this at the time, although as a mathematical proposition it did not exactly ring right to him; but he has taken the trouble to have compiled a set of statistics that, in connection with Mr. Johnson's paper, will prove

very interesting, and bear out the more widely distributed data submitted by him. In general all these figures show that there is not what you might call a corresponding decrease with either slow sand or mechanical filtration as to the total death rate when you consider the very great decrease of the typhoid death rate. As a matter of fact, in the Rhode Island communities where statistics have been available disclosing both slow sand and mechanical results we get a total death rate reduction that averages about 10 per cent; while the total average typhoid death rate runs around 46 per cent. It should be remembered that Rhode Island is a great manufacturing center, employing transient and foreign labor. Herewith are submitted these Rhode Island statistics for your inspection:

East Providence mechanical filters

YEAR	POPULATION	TOTAL DEATHS	RATE PER 1,000	TYPHOID DEATHS	TYPHOID RATE PER 100,000
1891	8,778	144	16.4	3	34
1892	9,170	159	17.3	3	33
1893	9,386	150	16.0	2	21
1894	9,773	171	17.4	3	31
1895	10,170	160	15.7	7	69
1896	10,572	156	14.7	3	28
1897	10,987	163	14.8	2	18
1898	11,432	123	10.8	0	0
1899	11,813	141	12.0	2	17
1900	12,138	211	17.4	6	50
1901	12,533	162	13.0	1	8
1902	12,851	171	13.4	4	31
1903	13,791	229	16.8	4	30
1904	13,328	204	15.3	0	0
1905	13,750	187	13.6	2	15
1906	14,072	221	15.7	2	14
1907	14,395	227	15.8	2	14
1908	14,717	213	14.5	2	14
1909	15,396	211	13.7	1	6
1910	15,808	233	14.8	0	0
1911	16,220	207	12.8	1	6
1912	16,632	194	11.7	1	6

Average eight years before filtration 1891–1898......	15.4	29
Average fourteen years after filtration 1899–1912........	14.3	15
	7 per cent reduction	48 per cent reduction

Comments on above table given to Mr. Milligan, April 27.

Providence (city) slow sand filters

YEAR	POPULATION	TOTAL DEATHS	RATE PER 1,000	TYPHOID DEATHS	TYPHOID RATE PER 100,000	TYPHOID PER CENT OF TOTAL DEATHS
1899	165,666	3,162	19.1	42	25	1.33
1900	175,597	3,678	20.9	39	22	1.05
1901	180,355	3,444	19.1	46	26	1.33
1902	186,294	3,394	18.2	38	20	1.12
1903	191,937	3,895	20.3	39	20	1.00
1904	194,027	3,593	18.5	29	15	0.81
1905	198,635	3,474	17.5	39	20	1.12
1906	203,243	3,816	18.8	40	20	1.05
1907	207,850	4,001	19.2	17	8	0.42
1908	212,458	3,570	16.8	35	16	0.98
1909	219,188	3,535	16.1	28	13	0.79
1910	224,326	3,982	17.7	40	18	1.00
1911	229,464	3,598	15.6	28	12	0.78
1912	234,602	3,722	15.8	25	11	0.67

Average seven years before filtration 1899–1905.......	19.1	21
Average seven years after filtration 1906–1912......	17.1	14
	10 per cent reduction	33⅓ per cent reduction

Bristol County mechanical filters

YEAR	POPULATION	TOTAL DEATHS	DEATH RATE 1,000	TYPHOID DEATHS	TYPHOID RATE 100,000	TYPHOID PER CENT OF TOTAL DEATHS
1900	13,144	297	22.6	4	31	1.35
1901	13,396	240	17.9	7	52	2.92
1902	13,595	250	18.4	2	15	0.80
1903	13,962	277	19.8	2	14	0.72
1904	14,667	264	18.0	5	34	1.89
1905	15,048	296	17.8	0	0	0
1906	15,429	257	16.7	1	7	0.39
1907	15,809	262	16.6	2	13	0.76
1908	16,190	249	15.4	1	6	0.40
1909	17,091	240	14.0	2	12	0.83
1910	17,602	325	18.5	0	0	0
1911	18,113	303	16.7	1	6	0.33
1912	18,624	296	15.9	2	11	0.67

Average eight years before filtration 1900–1907.......	18.5	21
Average four years after filtration 1909–1912..........	16.3	7
	12 per cent reduction	66⅔ per cent reduction

Newport (city) mechanical filters

YEAR	POPULATION	TOTAL DEATHS	RATE PER 1,000	TYPHOID DEATHS	TYPHOID RATE PER 100,000	TYPHOID PER CENT OF TOTAL DEATHS
1901	22,403	386	17.2	8	36	2.07
1902	22,670	424	18.7	8	35	1.89
1903	23,233	359	15.5	4	17	1.11
1904	24,438	340	13.9	4	16	1.18
1905	25,039	394	15.7	7	28	1.78
1906	25,559	339	13.3	4	16	1.18
1907	26,241	373	14.2	1	4	0.27
1908	26,842	342	12.8	2	8	0.58
1909	26,727	382	14.3	1	4	0.26
1910	27,149	383	14.1	5	18	1.31
1911	27,571	364	13.2	4	14	1.10
1912	27,993	405	14.4	3	11	0.74

Average nine years before filtration 1901–1909.......	15.1	18
Average two years after filtration 1911–1912.........	13.8	12½
	9 per cent reduction	31 per cent reduction

Mr. F. A. Dallyn: The last gentleman's remarks regarding vital statistics present a very interesting problem. The speaker stated that he himself had gone into the matter a few months ago in connection with the typhoid death rates in Ontario. Deductions based upon the total deaths are of very little value taken by themselves. The significance of total deaths is badly interfered with by the fact that the infant death rate is included in the total deaths. The infant death rate in cities is usually abnormal, due to the presence of institutions in those centers. The institutional death rate has been simply terrific in past years. Actual investigation in Toronto and Ottawa, two centers which have institutions for infants, showed that the death rate in those cities is abnormal, being about three or four times the rate for the surrounding rural districts; the congestion and the institutions are the primary causes for this excess. The infant death rate in some centers is almost half the total death rate. Possibly the best method of making a comparison between cities would be to exclude the infant death rate under five years, which would leave a rate that is probably sympathic for typhoid, the total deaths and bad water supplies.

MR. PAUL HANSEN: The speaker does not wish to refute Mr. Milligan's statement with reference to pressure filters; but does wish to say that pressure filters should not be adopted except with extreme precautions and in exceptional cases. In the first place, pressure filters are very inaccessible; in the second place, if operated as pressure filters, it is not feasible to use coagulation and sedimentation preliminary to filtration. Therefore it is not easy to get as good results as with the open type of filters.

In the state of Illinois we have one striking instance of how difficult it is to treat water with pressure filters, owing to the fact that it is not possible to secure good reaction with the chemicals and the proper sedimentation preliminary to filtration; if pressure filters are applicable at all they are applicable to waters that are already clear or nearly so, and which require merely slight filtration to give them the proper physical characteristics and then sterilization must be relied upon to take out objectionable bacteria.

MR. CHARLES B. BURDICK: The author states at the conclusion of the paper that the average cost of rapid sand filtration is $5.70 per million gallons, and that for slow sand filtration $7.33 per million gallons. The method for arriving at this cost is by taking the cost per million gallons of these plants and multiplying it by 5 per cent, that is, in computation of the fixed charges, and dividing it by 365, the number of days in the year. This computation of the fixed charges assumes that the plant operates at 100 per cent of its capacity throughout the year. The statistics of the several plants given here show that the various plants average very materially less than 100 per cent. Some of the plants noted, one particularly, have a percentage of operation as small as 40 per cent and somewhere around 85 per cent or 90 per cent is the highest rate, and that only in places where there are probably other sources of water supply than the particular plant mentioned. It is safe to say that throughout the life of a mechanical filtration plant or a slow sand filtration plant it is probable that the rate of delivery will not exceed perhaps two-thirds of the rated capacity day in and day out, under which circumstances it will be necessary to add about 50 per cent to the fixed charges mentioned here, which will result in cost around $10 for slow sand filtration based on these figures of cost of installation, and $6.50 for mechanical filtration.

Mr. H. F. Dunham: While it is true that every new piece of work must be regarded as a separate affair or problem, the questions of the greatest interest in this discussion cling around those general features which are common to all installations; the element of risk is such a feature. It seems to have been overlooked; it is more apparent in some designs than it is in others, and is more a factor in some classes of construction than in others, but it always persists, and pertains to time intervals as well as to the incidents of construction, and the failure of work after construction.

Let it be assumed a given object or purpose is to be accomplished by certain well defined means, or by one method, in a given interval of time. Then, if the same result can be reached by another method, involving construction expenditures only one-half or one-third as large, this second method is far in excess of the estimated difference in cost under favorable and known conditions; for it may be necessary to carry out the work under conditions that are not favorable and known.

Speaking generally, there is no doubt that a large area of land can be purchased at less cost per acre than a small area, but the large area cannot be covered with brick or concrete structures without involving greater risks. Bonding and insurance companies would recognize that fact. There is evidence to show that no class of filtration work is exempt from accident and failure.

Mr. H. C. Hodgkins: If the speaker has read this paper correctly the charge in one instance for interest and depreciation was 5 per cent; in Mr. Fuller's paper he gave the rate for interest and depreciation at 4.75 per cent. This calls to mind an article prepared by a member of this Association in which he undertook to work out a rate charge, and in which he figures out depreciation and interest charges at an average of 8 per cent; that paper is a matter of record.

Now it has impressed the speaker that, if he was putting some money into a filter plant of his own, he would want to see more than 5 per cent for interest and depreciation, the proper rate ought to be higher than that in estimating the cost of any engineering structure.

Mr. J. N. Chester: This discussion reminds the speaker of the old saying that the first story-teller "don't stand no show." If it comes to reciting costs, of course any cost may be questioned. The first filter with which the speaker was connected was a slow sand

filter, the third built in the United States; built and in operation along the New Haven Railroad thirteen miles from the Grand Central Station, New York City. It was built twenty years ago. The speaker was not called in to say that it should be built; but learned afterwards that the company, not the present owners, wanted to issue some bonds and they thought it would be a good thing to have some construction work in progress, so they commissioned him to build a filter plant. They did not ask for an estimate at all, but gave directions to build it. There were no plans made, other than a sketch on the back of an envelope. We succeeded in building a plant covering 1.4 acres for $22,000. We created that filter by damming off part of a reservoir. We took no precautions to keep out the ground water, of which we had considerable. We obtained our sand, which was excellent, from a bank adjacent to the site; our stone and our gravel came from the same source. We shipped in little. We used wooden boxes for under drains; we had no clear water basin other than a small suction well; and no sedimentation basin. You will allow that this plant should filter at least 4,000,000 or 5,000,000 gallons per day, so here is a slow sand unit with which you can compare.

We frequently get in our office a commission to design a small filter plant, and generally where a small filter plant is wanted there is a minimum amount of money available. It is not exceptional to build a half million gallon unit, or anywhere from that to a 1,000,000 gallon unit, at from $5,000 to $10,000. But how do we do it? Sometimes we put up two small wooden tubs that constitute the filters. We will probably put in wrought iron manifold systems. We will wash with direct pressure from high pressure mains. For sedimentation we may put in wooden tanks. For coagulant tanks we may set up a couple of barrels, and we will improvise the orifice boxes. We will use hand valves and wrought iron pipe throughout. When we get through they will have a filter plant that will probably filter as good as anybody's, but it will depreciate very rapidly and it will incur a high cost of operation. However, the state board of health has ordered them to filter. They have only so much money and they say, "Won't you please, Sir, design us a plant that we can put in with that amount?" But it is not fair to compare those prices with prices of up-to-date plants. When that Mount Vernon filter plant was built we paid $1 for the day laborer. We could stand over those men with a whip and crack it vigorously. We got

three days' work measured by the day's work that a man does today. It was in the worst part of the panic of 1893 and 1894, and we of course availed ourselves of the low price of labor, and paid nothing for the material, so it only cost the labor.

In earlier years, in designing and building filter plants we did not design such a plant as is ordinarily built today, but we put in a number of tubs or units and built a house over them. There are a great many of those filter plants over the country today.

Today when you start to build a 10,000,000 gallon or 20,000,000 gallon filter, you put a whole lot of money into what we call a "head house" or "coagulation house," or the administration building, or whatever you may please to call it. You will spend $2,000 or $4,000 or even $6,000 per million gallons for that element of the filter. You can design them for as little or as much as you or your client demands. The more you pay for, the more you have, and the less you pay for, the less you have. You take a half million unit filter plant, with hand-operated valves, 6 inches in size, and then you increase the size of the unit to 1,000,000 gallons and begin to think about hydraulic valves, and you will have to add several hundred dollars per million gallons for that single thought. It is easy to criticise someone's prices or someone's statement without analyzing.

Pressure filters *may* get a good hold again, but the speaker does not see just how they can be quite as acceptable as open filters; and his reasons for thinking so are something on the same line as Mr. Hansen's. You can put water into a sedimentation coagulation basin after first coagulating it, then pick it up with pumps and send it through the filters; but in so doing you handle your floc pretty roughly. The speaker does not say that pressure filters will not do good work, for the pressure type of filters at Little Rock and Chattanooga are still doing good work, but working under gravity pressure. They are not as desirable as open filters because we can not see what is going on. When you build such filters horizontal you get a curve on them that makes trouble. Mr. Weston can testify to that for he tested the first pressure filters that the speaker ever had to do with, and we found that there was clay in the segments of the filters that projected out over the strainers. Let the speaker say that he has found that same trouble in every horizontal filter with which he has had to do.

Finally regarding Mr. Hawley's comments and the results that

he shows, let the speaker caution you who are expecting such results that the credit is not due the filter company that built the plant or the engineers that did the designing, but the very careful manner in which it is operated.

Mr. George A. Johnson (*author's closure*): The author has read Mr. Gregory's discussion of his paper with much interest.

It is undoubtedly true, as Mr. Gregory states, that at Albany, Philadelphia, Pittsburgh, Cincinnati and Columbus the sites selected for the filtration plants, which were later built, were well advised. Nevertheless, the author still contends that there is always bound to be a wide difference in the cost of land for slow sand and rapid sand filter plants, the same roughly approximating a ratio of 20 to 1, as stated.

In citing his exceptions to the author's viewpoint, Mr. Gregory bases his conclusions that the above ratio is too high mainly upon the condition which sometimes obtains, wherein a large tract of land can be bought for a sum not much greater than that demanded for a small portion of the same tract. In such a case it may be, and often is, good business policy to acquire the larger tract, even though only a small part of it actually would be utilized for the filter plant. The balance would have a value that should not stand as a charge against the cost of land for the filter plant, and it might profitably be sold at some future time if desired. Does not, therefore, the relative cost of land for filter plants of the two types reduce itself to a proposition of actual area utilized? Giving to the slow sand filter credit for a normal rate of filtration of 5,000,000 gallons per acre daily, and to the rapid sand filter a normal rate of 120,000,000 gallons per acre daily, in a 20,000,000 gallon plant of each type, for the filters alone, 4 acres of land would be required for actual slow sand filter area as against 0.17 acre for actual rapid sand filter area. This is in the ratio of 24 to 1, and the additional ground required for basins, buildings and other parts of plants of both types will not reduce this ratio materially. Much larger preliminary settling basins are called for in slow sand filter installations than in plants of the rapid sand type. A reserve filtering area of some 10 per cent is demanded in plants of the slow sand type but not in plants of the rapid sand type; and numerous other items certainly will tend to hold close up to the mark the required land ratio of 20 to 1, as stated by the author.

With reference to Mr. Gregory's comments on costs of construction of slow and rapid sand filter plants, the author agrees with him that it is exceedingly difficult to satisfactorily compare such costs. Local conditions always control in a large measure, referring to the character of the raw water, topographical conditions, availability and cost of building materials, cost of labor, etc. As to reservoir capacities, they, too, control, but it is not to be denied that many rapid sand filter plants have been provided with needlessly large settling basins, whereas this is not true in the case of any slow sand filter plant of which the author has knowledge. If it were, then such improvements along the line of preparatory treatment as have been made at Albany, Washington, Pittsburgh and elsewhere, and such as are contemplated at Philadelphia, would have been unnecessary.

With reference to the cost of the Little Falls, New Jersey, plant, Mr. Gregory must know that the desire to avoid double pumping, coupled with the very small area of suitable land available and the necessity for building the plant on high ground above flood water levels, made imperative the strikingly deep basins found at that plant. These factors made the cost of this plant as high as it was. The coagulating basin provided may have been too small, judged by present practice, but the plant was built 12 years ago, before such things were as well understood as they are today. Nevertheless the cost of operation and results obtained at the Little Falls plant in the dozen years it has been in successful operation compare most favorably with those at any other filter plant of its type in the world. Owing to the existence of several large reservoirs on the distribution system a large clear-water basin was not called for. The one provided has proved to be of ample size.

The Columbus plant, which Mr. Gregory cites, is a water softening as well as a water filtering plant, therefore large settling capacity was called for. Lacking distributing reservoirs it was necessary to provide large filtered water reservoir capacity. It therefore is manifestly improper for Mr. Gregory to compare reservoir capacities at Columbus and Little Falls, as the controlling conditions at the two places are entirely different.

With reference to Mr. Gregory's comments on the Albany, New York, slow sand filter plant, it is true that its present daily capacity, due to the addition of preliminary filters to the original layout, and certain changes in methods of operation, may be as high as 28,000,000 gallons instead of 20,000,000 gallons, as stated by the author. But

the author wonders whether Mr. Gregory considers this plant in the light of a true slow sand filter, and if he has given thought to the possibility that, for a large part if not all of the time, the operation of the final slow sand filters might possibly be dispensed with, without affecting the efficiency of the plant as a whole. This being the case, perhaps it might be considered that the Albany plant is, to all intents and purposes, a rapid sand filter plant, in which event the cost of construction of such parts as are actually necessary would be far below the figure given by Mr. Gregory, namely, $14,300 per million gallons daily capacity.

The author agrees with Mr. Gregory that the Philadelphia slow sand filter plants were expensive.

The cost of the Toronto slow sand filter plant, mentioned by Mr. Gregory, was not unknown to the author; as extensions to the filtration system are being made along radically different lines, he did not consider it necessary to mention this plant. Furthermore, he was restricting his paper to United States practices.

The author would not change the weighted average cost of slow sand filters given in his paper in consequence of the arguments cited by Mr. Gregory, for the above reasons.

As regards the cost of the Columbus rapid sand filter plant, it is to be recalled that this is a water softening as well as filtration plant. The total cost of the filtration and softening works is given by Mr. Gregory as $17,750 per million gallons daily capacity (Trans. Am. Soc. C. E., vol. lxvii, 1910). The items which should be omitted from this figure, if the plant is to be considered as a water filtration plant, eliminating the softening feature, are those for the lime saturator house ($1080), and mixing tanks ($1470). On account of the necessity for providing large settling tanks wherein the softening reactions are completed an allowance should be made there. Instead of twelve hours' capacity three hours would be ample for filtration alone, hence from the item of $168,770 for the full twelve hours' settling capacity, or $5630 per million gallons daily filtering capacity, this item should be reduced to at least $2000, a reduction of $3630 per million gallons. The head house, while suitable in all ways for a combined water softening and filtration plant, is too large and contains apparatus of no use in ordinary water filtration. The same is true of the storage house which was made necessarily large to accommodate the huge reserve supply of softening chemicals.

From all the above it is clear to the author that his cost of $13,000 per million gallons for building the Columbus filtration works proper is entirely reasonable.

Much the same argument against Mr. Gregory's viewpoint as to the cost of rapid sand filtration works, where the softening accessories are eliminated, may be made in the case of the Grand Rapids plant, referred to by him.

As to the proposed rapid sand filter plant for New York City, mentioned by Mr. Gregory, the author, like Mr. Gregory, also served as one of a commission of consulting engineers on this project, and is therefore more or less familiar with the matter; and he knows that the cost per million gallons daily capacity, were it not for the unusually large clear water basin provided for this 320,000,000 gallon daily plant, namely, 365,000,000 gallons, would more nearly approach $12,500 per million gallons than the figure cited by Mr. Gregory. At that the low bid for the entire plant, including the large clear water reservoir, was $5,139,015, or $16,060 per million gallons daily capacity.

As to the Cincinnati rapid sand filter plant, the author differs from Mr. Gregory in the opinion that the large storage reservoirs, providing at the present time some six days' storage, should be considered a part of the filtration plant. He does not consider any such preliminary sedimentation of the raw Ohio River water necessary, nor would he provide it. In his recent consideration of rapid sand filtration for the city of Wheeling, West Virginia, he made no such provision, deeming it an unnecessary and uncalled for expense.

The New Orleans rapid sand filter plant, cited by Mr. Gregory, was an unusually expensive one to build, owing to bad foundation conditions, a point not mentioned by Mr. Gregory when stating the cost of this plant as $30,200 per million gallons daily capacity.

The author does not feel that Mr. Gregory's contentions are sound, or that he has made out a clear case that the author's cost for rapid sand filters is too low, and for slow sand filters too high. The author holds no brief for rapid sand filters, any more than Mr. Gregory does for slow sand filters, and in his paper merely cited a few examples which he had no idea would be taken as criteria of the relative cost of the two types of plants. In his closing remarks the author was particular to state:

Questions of cost alone should never govern the manner of dealing with problems affecting public health and comfort. It so happens, however, that slow sand and rapid sand filtration costs about the same, with the advantage of lower cost usually in favor of the rapid sand process. A human life is customarily valued at $5000 and a difference of even $15 per million gallons for water filtration, one way or the other, amounts in a year's time to about the value of one human life.

Mr. Maignen's remarks relative to the actual inefficiency of preliminary filters are interesting. Such filters had their origin in the desire to relieve the final slow sand filters of their occasional unbearable load of suspended matter. But, as Mr. Maignen says, they take out the coarse particles and allow the finer particles to pass onto the slow sand filter into which they penetrate to considerable depth, indeed sometimes passing entirely through them, as at Torresdale. Therefore, to make preliminary filters efficient it is necessary to use coagulants, and when the preliminary filters are properly built and operated and coagulants are used, of what earthly use are the final slow sand filters, particularly when the filtered effluent is sterilized?

Mr. Hawley's reference to the Pittsburgh filter plant may, perhaps, create an erroneous impression with respect to the exceedingly good work which is being done by that plant. Nevertheless the author is in thorough accord with Mr. Hawley in the belief that if the purification of the Allegheny River at Pittsburgh were to be considered as a new problem today, rapid sand filters would be adopted. The original plant, by virtue of highly skilled supervision, has done and is now doing excellent work; but as good, if not even better, work could be done by a regulation rapid sand filter plant, and the operation of such a plant would be far less difficult.

Mr. Hawley's description of the results obtained at the Wilkinsburg, Pennsylvania, plant are most interesting and instructive.

Regarding Mr. Chester's remarks on costs of construction, the author realizes, of course, that local conditions and local ideas largely control such matters. He knows that at some places the muddy character of the raw water makes it expedient to use larger settling basins than would be demanded at other places where the turbidity of the raw water is lower. Nevertheless he believes this idea has been carried much too far in some cases, as very muddy waters usually contain a large percentage of heavy sediment which will settle out in a very short time.

If it is desired by a given community to minimize the cost of the filtration works, then it assuredly can be done by cutting out what Mr. Trautwine calls "frills." Conversely, if civic pride impels another community to "go the limit" on such things, and make the works "a beauty and a joy forever," then the cost of the works will increase accordingly. In other words, it is perfectly possible to construct in a suitable manner, well appearing, fully equipped filter plants of modern design for the figures given in the author's paper, and do so without in the slightest degree impairing the stability or efficiency of the plant.

The author heartily agrees with Mr. Leisen that the whole subject covered by the author's paper should be thoroughly discussed without passion or prejudice, and has been pleased to note that for the most part the various discussions submitted have been along that line.

The author cannot subscribe to Mr. Weston's conclusion that for iron removal the slow sand filter is cheaper and better than the rapid sand filter. He wishes Mr. Weston had cited a few examples and experiences to support his statement.

Mr. Armstrong's statement that the cost of the Baltimore rapid sand filter plant, now building, will be less than $12,000 per million gallons, comes from a source, the reliability of which must be recognized. It merely goes to show that whether or not some rapid sand filter plants have cost more than $12,500 per million gallons capacity, there are many which have been and are being built for even less.

Mr. Trautwine's historical sketch of the development of the filtration problem in Philadelphia is most interesting. It still remains a good deal of a mystery to many others besides Mr. Trautwine why the slow sand process was finally adopted at Philadelphia.

Mr. Milligan's discussion of construction cost factors, and the relative applicability of slow and rapid filters for iron removal is along the line of the author's own ideas.

One point brought up by Mr. Milligan the author wishes to comment on at length. This refers to the statement, or suggestion, made on March 10, when the author addressed the New York Section of this Association on the subject matter of this paper. The statement referred to was in effect that whereas with both types of filters there followed about the same reduction in the typhoid fever death rate among the consumers, the total death rate was materially

reduced among the users of slow sand filtered water while among the users of rapid sand filtered water such reductions were not noted; in fact in some instances sharp increases in the total death rate had followed the introduction of rapid sand filters.

This statement created considerable of a sensation, and accordingly the author wrote to the health authorities in several cities for data bearing on the point in question. In the following table (p. 516) the data received from eight slow sand and seven rapid sand filter cities are presented in detail.

So far as such statistics may be relied upon, and they are all that we have from which to judge such things, it is seen that, speaking broadly, there is nothing to choose between the two systems so far as concerns the relative reduction in the total death rate and the typhoid fever death rate as the result of filtration of the water supply. This is made somewhat clearer in the following table wherein the figures given in the foregoing table are condensed. Mr. Milligan's figures tell the same story.

Total death rate and typhoid fever death rate in cities before and after filtration

CLASSIFICATION		KIND OF FILTRATION	
		Slow Sand	Rapid Sand
Total death rate per 100,000	Before filtration	1863	1883
	After filtration	1688	1778
Typhoid death rate per 100,000	Before filtration	70	64
	After filtration	27	22
Per cent reduction after filtration	Total	9	6
	Typhoid	61	66

It is perfectly clear why this should be and is so. The typhoid fever death rate is reduced equally by both systems, but variations in the total death rate, which is many times the typhoid fever death rate, are caused by outbreaks of specific diseases other than typhoid fever and due to other than water-borne diseases. Infantile diseases, accountable for a higher infantile death rate some years than others, probably are responsible for the majority of sharp variations from the normal in the total death rate. Improved general sanitary conditions will always be followed by a decreased total death rate. Campaigns for purer milk supplies, fly elimination, improved hospital facilities and so on, will always effect a reduction in the total death rate.

Total death rates and typhoid fever death rates before and after filtration of the public water supply
(Compiled from data kindly furnished by the health officials in the various cities named)

KIND OF FILTRATION			SLOW SAND								RAPID SAND						
City			Pittsburgh, Pa.	Washington, D.C.	Albany, N. Y.	Philadelphia, Pa.	Springfield, Mass.	Indianapolis, Ind.	Wilmington, Del.	Lawrence, Mass.	Binghamton, N. Y.	Youngstown, O.	Burlington, Vt.	Cincinnati, O.	Watertown, N. Y.	New Orleans, La.	Columbus, O.
Total death rate per 100,000 population	Years Before Filtration	5	2110	2130	2160	1770	1430	1340		2192	1530	1340	2260	1830	1980	2220	1610
		4	1970	2010	2070	1889	1540	1230	1642	2566	1740	1480	2160	2060	1740	2350	1490
		3	1950	2020	2250	1856	1490	1180	1556	2652	1840	1530	2530	1890	1510	2140	1530
		2	1920	2080	2500	1740	1460	1240	1464	2446	1980	1605	2520	2020	1690	2340	1550
		1	1830	2040	2630	1886	1370	1290	1464	2614	1890	1725	2360	1810	1900	2220	1520
	Years After Filtration	1	1730	2030	1950	1859	1570	1210	1751	1897	1810	1685	2180	1800	1710	2020	1400
		2	1580	2010	1880	1744	1470	1200	1625	2032	1490	1500	2310	1630	1930	2140	1540
		3	1790	1980	1710	1623	1430	1230	1557	2030	1880	1593	2060	1740	2260	2040	1430
		4	1490	1910	1910	1729	1630	1100	1433	2058	1900	1446	2120	1690	1320	2020	1440
		5	1590	1960	1930	1650	1550	1110		1974	1840	1541	1930	1730	1570	1990	1530
Typhoid fever death rate per 100,000 population	Years Before Filtration	5	134	60	134	44	18	45		113	42	87	6	43	65	36	135
		4	142	78	72	69	24	34	34	126	75	124	11	81	65	32	73
		3	99	48	88	53	14	42	30	134	52	118	22	45	76	30	34
		2	130	47	94	48	25	49	21	119	58	116	11	68	90	55	36
		1	125	47	74	72	20	73	24	105	70	80	21	44	214	33	104
	Years After Filtration	1	49	52	39	59	23	35	32	49	35	52	10	18	26	29	17
		2	25	36	22	35	20	33	24	34	14	48	10	13	54	32	16
		3	28	39	29	21	9	29	24	26	17	31	5	6	40	31	14
		4	26	35	20	17	11	27	15	25	19	38	0	12	42	14	20
		5	13	24	20	14	8	20		24	17	30	5	8	33	16	19
Average total death rate	Before filtration		1956	2056	2320	1829	1460	1256	1531	2494	1796	1536	2366	1922	1764	2254	1540
	After filtration		1636	1980	1880	1721	1530	1170	1591	1998	1784	1553	2120	1718	1758	2042	1470
Average typhoid death rate	Before filtration		126	56	92	57	20	49	27	119	59	105	14	56	102	37	76
	After filtration		28	37	26	29	14	29	24	32	20	40	6	11	39	22	17
Per cent reduction following filtration	Total death rate		12	4	18	6	*5	7	*4	20	1	*1	10	11	0	9	4
	Typhoid death rate		78	34	72	50	30	41	11	73	66	62	57	80	62	40	78

* Increase

Mr. Dallyn's comments relative to the necessity of eliminating the infant death rate in order to obtain something like a definite value from vital statistics is a point well taken.

As to Mr. Hansen's comments on pressure filters, the author is of the opinion that the main reason why they are not in such favor as gravity filters is that in the past they have been looked upon as automatic and requiring but very little attention. They are not so capable of control as are gravity filters, and consequently are more liable to go wrong. But if the effluent is sterilized they certainly have a field of usefulness which is by no means small. In other words water sterilization, as developed in the past five or six years, will do as much toward furthering the field of usefulness of pressure filters as for any other type of filter.

Mr. Burdick's contention relative to the actual cost of filtration, based on the ground that most filtration plants operate at only some two-thirds their full capacity throughout the year, has considerable merit. He believes on this account that the fixed charges mentioned by the author should in some cases be increased by about 50 per cent. Now in a measure this is true. Of course it cuts both ways, perhaps, other things being equal, a little deeper with slow sand filters on account of the greater reserve areas required. But it has always been the custom to design filtration plants of capacities considerably in excess of immediate needs in order to anticipate emergencies. A filter plant must be prepared to handle peak loads, for water consumptions vary greatly with the seasons, and increased water consumption frequently is to be expected following the substitution of pure filtered water for the former impure and unsightly supply. The average daily consumption throughout a given year cannot be taken as governing the size of filter plant to be built.

To Mr. Dunham's comments regarding the element of risk entering into questions of cost of construction the author would state his entire coincidence.

In some measure Mr. Hodgkins is right on the proposition of 5 per cent interest charges; but he includes depreciation. The figure used by the author was for interest on the investment, solely, but feeling that the comparison between the two types of filters was not thereby affected, and since he was not striving at exceptional accuracy as to costs, as the closing paragraph of his reply to Mr. Gregory's discussion will show, perhaps he was not any too specific. Even in these hard times, though, there is still considerable money,

on relatively large investments, to be had at even less than 5 per cent.

The author notes Mr. Whipple's statement that the rapid sand process predominates at the present time, and in view of what Mr. West has to say about the proposed changes at the Torresdale plant, and what is being done at Albany and elsewhere, it seems very clear to the author that the degree of predominance of the rapid sand idea is much greater than appears on paper at this date.

It is very true that the use of oxygenated compounds of lime and soda has materially broadened the field of filtration in general, and the author knows that this applies with quite as great force to slow sand filter plants as to rapid sand filter plants, probably more in the case of the former, which are well known to show greater evidences of hygienic failure in the colder months of the year.

Mr. Whipple's strictures regarding the cost statistics given by the author are graciously noted. These figures were merely shown in a suggestive way, and were not intended to be taken as criteria. Nevertheless the author would appreciate having Mr. Whipple exercise his well-known statistical ability, and give to the profession the complete data on comparative costs he seems to think necessary. The author trusts that when Mr. Whipple attempts this trifling task he will detail all his figures and not lay himself open to the criticism he himself directs at the author.

Mr. Whipple criticises the author's statement that slow sand filters are out of their element when chemicals are used in connection with their operation, and states that by studying the cost and results of operation at Springfield, Massachusetts, and Washington, D. C., one may learn that chemicals may be economically applied with great benefit. Looking at the matter broadly, however, the author believes his own position to be prefectly correct. Furthermore, he cannot refrain from quoting in this connection the sound and logical conclusion of Mr. Allen Hazen, in his book, *Clean Water and How to Get it* (1914, pp. 95–6).

> Sand filters are used in connection with various preliminary treatments, but, generally speaking, they are adapted to treating only such waters as are capable of being purified in that way without any preliminary treatments, or with only rough and inexpensive treatments. If the water ordinarily requires coagulation, then, as a rule, it will be better to make the coagulation thorough and use mechanical filters for the final treatment.

As to the hygienic efficiency of filtration, the author is inclined to believe with Mr. Whipple that it actually is nearer 100 per cent than 70 per cent, as stated by the author, the residual typhoid in cities having well built and well operated water filtration works coming from other sources than the public water supply. He is gratified to note that Mr. Whipple agrees with him in that water filtration is capable of preventing the spread of water-borne diseases, and that from a hygienic standpoint there is little to choose between the slow sand and rapid sand filtration processes.

The author differs from Mr. Whipple on the proposition that poor operation of rapid sand filters is likely to do more damage than poor operation of slow sand filters. Neither type of filter will run itself, and if anything happens to a slow sand filter it is out of commission for days, while with a rapid sand filter the error, if such occurs, can be, and usually is, remedied almost at once. He agrees with Mr. Whipple, however, that it is far more difficult to secure in small plants the high degree of expert supervision ordinarily true in large plants. This is not a fault or weakness of filtration processes but due entirely to local politics and false ideas of economy.

As to Mr. Whipple's closing remarks, the author has never denied that slow sand filtration may have a field of usefulness, but it certainly is a small one as shown by facts published by others than the author. Mr. Whipple is clearly mistaken in his assertion that most engineers have long since ceased to talk about the relative merits of slow sand and rapid sand filtration, for it is a fact that the majority of engineers have foresworn such undivided allegiance as they may formerly have held to the slow sand process, and are now supporting the rapid sand process. The developments of the last ten years alone prove that.

The author agrees with Mr. Caird that something might have been said about the status of filtration practices abroad. He thought, however, that one bite at a time, reasonably well Fletcherized, was about enough, and accordingly restricted his efforts to the United States. He would say, however, that in western Europe, where the waters are relatively clear, the slow sand filter still predominates, although there are notable examples of rapid sand filters in that region, as at Trieste, Austria; Posen, Germany; and Helsingfors, Finland. In the Far East, India and Egypt, where the raw waters usually are muddier and more nearly to be compared with our cen-

tral western waters, the rapid sand process has made great strides in recent years; the more notable of the recent installations of plants of that type being those at Cairo, Egypt; Bangalore, Dacca and Hubli, India; Bankok, Siam; Taihoku, Formosa; Inkao, Manchuria; and Kyoto, Japan. The last named plant treats the waters of Lake Biwa, which are rarely very muddy, as we understand the term.

Altogether there are rapid sand filter plants scattered throughout Canada, Mexico, Colombia, Australia, England, Scotland, Finland, Holland, Roumania, Austria, Russia, Egypt, India, Siam, China, Japan and elsewhere, having at the present time a daily filtering capacity of about 150,000,000 gallons.

Mr. Caird's comparison of results obtained at the Washington, D. C., slow sand filter plant, and at the Elmira, New York, rapid sand filter plant, are interesting and instructive.

With reference to Mr. Caird's conclusion that strainer heads are to be preferred to the newer form of underdrains where wire or perforated plate screens are placed over concrete channels containing gravel, the author was interested in noting, during a recent visit to the Cincinnati, Ohio, plant, that as fast as these screens fail at that plant they are being dispensed with entirely, having proved of no advantage.

Mr. Ellms furnishes vital statistics from Cincinnati which further demonstrate the untenability of the idea that while with slow sand filtration the total as well as the typhoid death rate is markedly diminished, with rapid sand filtration such reductions in the total death rate are not noted. His data are convincing, and it is thought that by taking these figures, together with those appearing in Mr. Milligan's discussion, and the author's contribution in connection with the same, this perfectly weird assumption (and it is nothing more) has been shown up in its true light.

Mr. Fuller's well-balanced, fair and logical statements are a source of much gratification to the author who finds no occasion to comment upon them for the reason that his own thoughts are in entire accord with the views expressed by Mr. Fuller.

Mr. Buerger furnishes some valuable figures on the cost of construction of slow sand and rapid sand filter plants, but the author will not comment upon them specifically, merely taking occasion to state that as many more examples could be given where the costs would be all the other way. As an example, take the Trenton,

New Jersey, rapid sand filter plant, which is now nearing completion. This plant has a daily capacity of 30,000,000 gallons, and represents, to the author's way of thinking, a very good example of a thoroughly well-equipped, modern, compact water filtration plant, devoid of unnecessary embellishments, but in all ways architecturally presentable. This plant, omitting the cost of the low-lift pumping equipment, but including everything else, will cost $12,000 per million gallons capacity.

Prompted by Mr. Buerger the author finds that he did inadvertently include a pumping station charge of $1.24 for the cost of operation of the Washington, D. C., filtration plant. This reduces the weighted average given by the author as the cost of operation of the seven slow sand filters by $0.15 per million gallons.

Mr. Buerger's remarks regarding improvements in the design of preliminary filters are interesting, but unlike Mr. Buerger the author does not feel that there will be any preliminary filters in 1922.

Mr. West's discussion, to the author's way of thinking, is of much value for the reason that the views of one who has under his immediate charge the largest filter plant in America are views which safely may be taken with very little, if any, salting.

His statement that when the Torresdale plant has been altered so that coagulants may be used in conjunction with the present preliminary rapid sand filters it will be possible to by-pass the final slow sand filters for nearly 80 per cent of the time is one which may surprise some, but which is no surprise to the author, who worked on the Philadelphia water problem over a dozen years ago, and realized it then.

Mr. West calls attention to the fact that the author made no particular reference in his paper to the use of sterilizing agents in connection with filtration. This is true, but in a former paper, written for the United States Government (Water Supply Paper No. 315,1913, pp. 71–2) the author stated:

> Where waters are unsatisfactory in physical appearance and are also polluted and require filtration, the combined use of filters and the hypochlorite process is called for. As an adjunct to filtration processes it (sterilization) has a distinct field of applicability, for at a moderate cost it insures a water above suspicion. Furthermore, there is brought about a considerable decrease in the first cost of the filtration plant. This is made possible by the use of higher rates of filtration, and the required filter area may therefore be reduced. It also effects a substantial economy in the cost of operation.

Mr. West's comments relative to the shortening of runs on slow sand filters, due to microscopic growths, are interesting. In an address delivered at the Milwaukee convention of the American Public Health Association, in 1910, the author cited as one of the advantages of the hypochlorite process, the fact that it brings about reduced clogging of the filter beds with a consequent lengthening of the runs between cleanings, due to the destruction of various forms of algae.

In closing it appears that a statement is required from the author in reply to certain insinuations which appear here and there in the various discussions of his paper, indicating that it seems to be the idea of some that he holds a brief for the rapid sand filter process.

So far as the comments contained in his paper may be so interpreted, and because of his thorough belief in the entire applicability of the rapid sand process to any and all water purification problems, he certainly has spoken in favor of that process in no uncertain terms, and in that light perhaps may be considered as holding a brief for it, but wishes to be understood as being without the slightest prejudice. The author prepared this paper for the Association because of an earnest desire to set forth a few plain facts which up to now have been given but scant, fragmentary and scattering publicity. He realized in the beginning that the truth might be distasteful to some; that he certainly was laying himself open to criticism for seeming bias, and even might be accused of perverting the facts to the advantage of the process he considered superior. Nevertheless it has always been his habit to express his beliefs in plain and unvarnished fashion, and back them up with actual data. He thinks he has done so in this case; and if unconsciously he has prepared a brief for rapid sand filters merely because of a desire to set forth the truth as he sees it, he cannot see that there is any help for it now and is prepared to accept the consequences, whatever they may be.

Finally, and at the risk of a paradox, to the author's mind the most interesting feature of a paper of this kind is the opposition it develops. He trusts he has answered in an adequate manner such dissenting comments as appear in the discussion, and desires to express his full appreciation to those who participated in the discussion, for many new thoughts have been brought out in a material fashion which add to whatever value the paper may possess.